EFFECT OF ENERGY SUPPLEMENTATION FROM BY-PRODUCT FEED PELLETS ON PRODUCTIVITY AND NUTRIENT UTILIZATION OF CATTLE GRAZING STOCKPILED CRESTED WHEATGRASS (*Agropyron cristatum* L.).

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ABSTRACT

Three experiments were conducted to determine the effects of source (experiment 1), frequency, and level (experiments 2 and 3) of energy supplementation on performance, forage utilization and intake, productivity, rumen fermentation, and nutrient digestibility of growing beef cattle fed stockpiled forage. In experiment 1 (EXP1) and experiment 2 (EXP2), 45 cross bred yearling steers were managed on stockpiled crested wheatgrass pasture over 70 days during summer/fall of 2011 and 2012. Steers were stratified by IBW (EXP1 = 334±1.2 kg; EXP2 = 358±1.8 kg) and allocated randomly to 1 of 9 crested wheatgrass pastures (5 steers/pasture). Each pasture was randomly assigned to 1 of 3 replicated (n = 3) treatments. In EXP1, two isonitrogenous and isocaloric by-product feed pellets that differed in starch and degradable fiber content were used in one of three supplementation strategies: 1) no supplement (CON), or supplemented at 0.6 % of BW with 2) low starch/high fibre (LS/HF) pellet (40.3% starch; 29.5% NDF DM basis) pellet, or 3) high starch/low fibre (HS/LF; 48.6% starch; 22.8% NDF DM basis) pellet. In EXP2 a by-product feed pellet was formulated to provide ruminal and post-ruminal energy (30.3 % NDF; 32.0 % starch; 7.2 % fat) supplementation strategies included: 1) daily (DLY) supplementation at 0.6 % of BW, 2) low-alternate (LA) supplementation at 0.9 % of BW, and 3) high-alternate (HA) supplementation at 1.2 % of BW. There was no effect ($P > 0.05$) of treatment on forage utilization in either experiment. In EXP 1, final BW and ADG were not different ($P > 0.05$) between LS/HF (435 kg; 1.4 kg d^{-1}) and HS/LF (439 kg; 1.5 kg d^{-1}). However, supplemented cattle had higher ($P < 0.05$) final BW and ADG than CON cattle (402 kg; 1.0 kg d^{-1}). Supplementation increased production costs by 450 %. In EXP 2, no difference ($P > 0.05$) was observed for final BW and ADG among DLY (435 kg; 1.1 kg d^{-1}), LA (424 kg;

0.9 kg d^{-1}), and HA (428 kg; 1.0 kg d^{-1}). Production costs were reduced by 23 % with alternate supplementation and LA had 19 % less production costs than HA.

In experiment three (EXP 3), four ruminally cannulated beef heifers were individually fed a stockpiled grass hay and offered the same pelleted supplement as in EXP2. Treatments consisted of 4 supplementation strategies: 1) no supplement (CON), 2) daily (DLY) supplementation at 0.6% BW, 3) low-alternate (LA) supplementation at 0.9 % of BW, and 4) high-alternate (HA) supplementation at 1.2 % of BW. Forage intake, rumen fermentation parameters, and apparent total tract digestibility were measured. Three data sets were analyzed: 1) overall (average of all collection days), 2) day of supplementation (DS) and 3) non-supplementation day (NSD) for alternating treatments. Overall, hay DMI (kg d^{-1}) was lower (P = 0.04) for DLY (7.1) vs. CON (8.1), but no different ($P \geq 0.11$) for DLY vs. LA (6.9), or vs. HA (6.4). On DS, hay DMI (kg d^{-1}) of DLY (7.3) differed ($P < 0.05$) vs. HA (6.0), but was not different ($P = 0.16$) vs. LA (6.4). On NSD, hay DMI (kg d^{-1}) of DLY (7.0) was not different ($P \geq$ 0.48) to those of LA (7.3) and HA (6.9). Overall, total VFA concentration (m*M*) was lower ($P <$ 0.01) for CON (69.2) vs. DLY (77.1); but not different ($P \geq 0.45$) for DLY vs. LA (75.8) or HA (75.1). Rumen NH_3 (mg/dL) was lower ($P < 0.01$) for CON (3.4) and higher ($P < 0.01$) for LA (5.8) vs. DLY (4.6), but not different ($P = 0.37$) for DLY vs. HA (4.3). Overall, ruminal pH was lower ($P \leq 0.04$) for DLY (6.65) vs. CON (6.75) and HA (6.72), but similar ($P = 0.18$) for DLY vs. LA (6.70). On DS, ruminal pH was lower ($P = 0.04$) for HA (6.59) vs. DLY (6.64), but higher ($P < 0.01$) on NSD for HA (6.85) vs. DLY (6.67). Apparent DM, OM and GE digestibility coefficients were lower ($P \leq 0.03$) for CON and LA vs. DLY, but no difference ($P \geq$ 0.36) for DLY vs. HA.

These results indicate that beef steers grazing stockpiled crested wheatgrass were limited in energy intake and that supplementation of metabolizable energy improved animal performance regardless of the source of energy. Reducing the frequency of energy supplementation and level offered on alternate days do not affect animal performance and reduces the production costs of the system. Negative effects of alternate day supplementation on forage intake and rumen fermentation are reduced when a lower level is offered relative to simply doubling the daily amount of supplement.

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LIST OF ABBREVIATIONS

ADF	Acid detergent fibre
ADG	Average daily gain
AOAC	Association of Official Analytical Chemists
BW	Body weight
Ca	Calcium
CP	Crude protein
d	Day
dL	Deciliter
DDG(S)	Dried distillers' grains (with solubles)
DE	Digestible energy
DIP	Degradable intake protein
DM	Dry matter
DMI	Dry matter intake
FBW	Final body weight
g	Gram
IBW	Initial body weight
IVDMD	*In vitro* dry matter digestibility
kg	Kilogram

mL	Millilitre
N	Nitrogen
NDF	Neutral detergent fibre
NFC	Non-fibre carbohydrates
NH_3-N	Ammonia nitrogen
NSC	Non-stuctural carbohydrates
OM	Organic matter
RDP	Ruminal degradable protein
RUP	Ruminal undegradable protein
SAS	Statistical Analysis Systems
SD	Standard deviation
SEM	Standard error of mean
TDN	Total digestible nutrients
VFA	Volatile fatty acid

1. General Introduction

Feed represents the highest portion of the total costs in the livestock industry (Anderson *et al*. 2005). Furthermore, feeding expenses can be increased by adverse environmental factors. An example of this situation is the beef cattle industry in Western Canada that every year has to deal with a winter season during which pastures are not available and feeding demands for animal maintenance are higher. Grazing, being the most cost effective way of feeding ruminants, and grazing management strategies such as extending the grazing season help beef producers in temperate regions reduce winter feeding costs (Baron *et al.* 2004; Frame *et al.* 2004).

However, grazing is not necessarily the most biologically efficient way to feed ruminants, especially when cattle are exposed to a diminished forage quality which is characteristic of extended grazing season practices such as stockpiled perennials and grazing annual crops. Grazing management strategies need to be developed in a manner that allows maximum production per land unit in a cost effective manner, and supplementation of grazing ruminants is one of the most important aspects to consider when making management decisions (Caton and Dhuyvetter 1997). A strategic supplementation program, that helps to maximize productivity of grazing cattle, is the most practical of these managing strategies. Research has shown that performance of beef cattle fed forage based diets can be improved by supplementation of digestible energy and/or protein, but the nature of the offered supplement, the interaction between supplemental energy and protein and the type of forage fed can result in different responses (DelCurto *et al.* 2000; Bodine and Purvis 2003).

In general, protein supplementation of low-quality forage increases both forage dry matter intake and animal performance while energy supplementation has been shown to reduce or have no effect on forage intake while increasing performance. Moreover, supplementing energy needs to be paired with adequate protein availability in order to avoid negative effects on intake, digestibility, and tissue deposition. Also, cattle grazing or fed warm season grasses have been shown to respond better to nitrogen supplementation, whereas ruminants fed cool season grasses can achieve a better performance through energy supplementation. However, supplementation brings an additional expense into beef production systems. These include the cost of the supplement and the cost of delivering the supplement every day, especially in extensive grazing systems (DelCurto *et al.* 2000; Kunkle *et al.* 2000). Available and less competitive ingredients as well as offering supplements less frequently can be used to minimize the increasing effect that supplementation activity has on feeding costs.

Western Canada is among the largest cereal and oil grain producers in the world, and by-product feeds obtained from the milling processes are suitable for animal feeding. The effects of supplementing by-products such as grain screenings, wheat middlings, various type of crop hulls and distillers' grains from ethanol production have been evaluated and confirmed their potential when added individually to beef cattle rations (Marx *et al.* 2000; Mustafa *et al.* 2000a; Klopfenstein *et al.* 2008; Pylot *et al.* 2000b; Thompson *et al.* 2002). However, little or no research has been conducted blending these ingredients and evaluating their combined effects on growing beef cattle fed forage basal diets.

Numerous studies have consistently shown that frequency of protein supplementation can be reduced without affecting animal performance (Krehbiel *et al.* 1998; Huston *et al.* 1999; Farmer *et al.* 2001; Bohnert *et al.* 2002). In contrast, fewer studies have been carried out evaluating the effects of less frequent energy supplementation. The results from these studies indicate reduced forage intake and cattle performance. These negative effects can be attributed to disturbed rumen fermentation, diet substitution effect and a partial consumption of the supplement (Drewnoski *et al.* 2011; Kunkle *et al.* 2000).

These animal disturbances are due to the fact that when the supplement is fed on alternate day feeding programs, the offered amount has been increased to achieve an equivalent weekly intake of the supplement. To date, no research has attempted to reduce the supplemental energy amount in alternate day supplementation programs to a level that does not necessarily meet the daily amount on a weekly basis.

The objectives of this literature review are to provide an overview of the stockpiling perennials as a suitable technique of extending the grazing season; to review the origin, characteristics, extension, and use of crested wheatgrass within the grazing beef cattle systems in North America, more specifically in western Canada; to review the animal performance of cattle grazing crested wheatgrass at different stages of maturity; to review the effects of supplementation and its frequency on the response of grazing cattle; and to review the various types of by-product feeds used as supplements in beef diets.

2. Literature Review

2.1. Extending the grazing season

Cool season forages are not capable of meeting nutritional requirements of cattle during the summer and fall months, and cool season pastures dominate the Canadian prairies (Barnes *et al.* 2003). However, adequate forage management throughout the season will provide an extended grazing season and subsequently decrease requirements for stored forage and/or supplementation during the fall-winter period (Gunter *et al.* 2002). Stockpiling perennials and grazing annual crops are common strategies to extend the grazing season, and can increase profitability by reducing the need for intensive winter feeding programs in beef cattle systems (Adams *et al.* 1996).

2.1.1. Stockpiled perennials

By definition, stockpiling pasture is the accumulation of forage for grazing after the growing season (Riesterer *et al.* 2000). Stockpiling perennial forage species is a practical and cost-effective practice to extend the grazing season (Baron *et al.* 2004). This technique allows beef cattle producers to reduce the cost of harvesting, hauling and feeding of conserved forage, as well as manure removal due to cattle spending more time on stockpiled pasture instead of conventional drylot winter systems (Johnson and Wand 1999; Riesterer *et al.* 2000).

Although almost any forage species can be stockpiled, quality of cool-season grasses is less affected than warm-season grasses as the season progresses due to their capacity of adaptation to lower temperatures (Johnson and Wand 1999; Cherney and Kalenback 2003; Lacefield *et al.* 2006). In a 3year study, Baron *et al.* (2004) evaluated the stockpiling potential of several perennial forage species adapted to the Western Canadian Prairies. It was concluded that meadow bromegrass (*Bromus riparius* Rhem.) and creeping red fescue (*Festuca rubra* L.) are the most attractive for stockpiling; while crested wheatgrass (*Agropyron cristatum* L.), smooth bromegrass (*Bromus inermis* Leyss.) and orchardgrass (*Dactylis glomerata* L.) also have potential as species that can be used to stockpile forage for later use.

2.2. Crested wheatgrass

Crested wheatgrass (*Agropyron spp.*) was first brought to North America from north-central Asia during the late 1800's and early 1900's, and played an important role in revegetation of the Northern Great Plains in the mid-1930's becoming the most effectively introduced perennial grass in this region (Holecheck 1981; Rogler and Lorenz 1983) . Crested wheatgrass is a bunchgrass with a deep, extensive root system that makes it resistant to extremely low temperatures, severe drought and heavy grazing conditions (Holechek 1981; Smoliak and Bjorge 1981). Longevity and persistence under adverse conditions, strong competitive capacity, ease of establishment, high forage productivity, good seed production, seeding vigor and relatively few disease problems are among the reasons for the widespread use of crested wheatgrass across western Canada and the United States (Rogler and Lorenz 1983).

Crested wheatgrass exhibits early spring to early summer (mid-April to mid-June) growth when forage is palatable and high in nutritive value, but a rapid and constant decrease in palatability as well as digestible protein and energy occurs once it has reached its mature stage (Daugherty *et al.* 1982; Hart *et al.* 1983; Hoffman *et al.* 1993). In a study conducted in southwestern Saskatchewan by Glover *et al.* (2004), nutritive value of crested wheatgrass (*Agropyron desertorum*) consistently decreased for crude protein (14.3 to 6.4 %) and phosphorus (0.41 to 0.16 %) when analyzed at three different growth stages (three-leaf, heading and seed set). A similar tendency was reported by Van De Kerckhove (2010) for nutritive value of stockpiled crested wheatgrass where CP content decreased 1.9 % while both neutral and acid detergent fibre content increased 4.3 and 4.8 %, respectively, over the fall. Looking at seasonal dynamics of forage nutrients for ungulate species, Memmott *et al.* (2011) collected and analyzed samples of crested wheatgrass from a sagebrush-grass mix from mid-May until late December in the same year and concluded that crested wheatgrass offered adequate nutrition to meet requirements of most ungulates during the first part of the grazing season, but decreased severely during the final part.

2.2.1. Supplementation of cattle grazing crested wheatgrass

Growing cattle grazing early season crested wheatgrass are able to maintain daily gains close to one kg per day. However, as the pasture matures, animal performance decreases along with forage quality (Frischknecht *et al.* 1953; Daugherty *et al.* 1982; Ojowi *et al.* 1996). Research has shown that performance of cattle grazing mature crested wheatgrass was improved when nutrient supplementation was provided. In a 2 year study, Wallace *et al.* (1963) supplemented yearling beef cattle grazing crested wheatgrass from mid-May until the beginning of September with energy (barley), protein (cotton seed meal), or a combination of both. They reported that cattle gained on average 0.18 kg d^{-1} more when energy was supplemented compared to no energy supplementation, 0.19 kg d^{-1} more when protein was supplemented compared to no protein supplementation, and 0.52 kg d^{-1} when both energy and protein were offered compared to a non-supplemented group. More recently, Ojowi *et al.*, (1996) reported that average daily gain of cattle increased when thin stillage was offered (1.39 kg d^{-1}) compared to when water was offered (0.91 kg d^{-1}) to growing steers grazing crested wheatgrass. Clark *et al.* (2009) observed similar performance (1.4 kg d^{-1}) when backgrounding steers grazing crested wheatgrass were supplemented with either barley grain, wheat dried distillers' grains with solubles (DDGS), and a 50:50 blend of both barley and wheat DDGS.

2.3. Supplementation of grazing cattle

Cattle fed forage-based diets are deficient in energy (Moore *et al.* 1999), minerals (McDowell 1996), and protein as long as the limiting factor is the quality not the quantity of forage (DelCurto *et al.* 2000). More specifically, cattle grazing rangelands are also limited in these nutrients and the necessity of supplementation is the greatest nutritional challenge for beef producers (Holechek and Herbel 1986; DelCurto *et al.* 2000). Correcting nutrient deficiencies, improving forage utilization and animal performance, and increasing economic returns are among the reasons listed for feeding supplements to cattle consuming forage-based diets (Kunkle *et al.* 2000). Supplements generally increase performance of forage fed cattle, and both supplemental protein and energy are needed in order to increase intake of low quality forage and performance of growing beef cattle (Moore *et al.* 1999; DelCurto *et al.* 2000). Furthermore, energy and protein metabolism in growing cattle are highly related; for instance, total energy and protein intake needs to be balanced through supplementation, in order to optimize nutrient utilization and animal performance (Bodine and Purvis 2003; Schroeder and Titgemeyer 2008).

2.3.1. Energy supplementation

The very nature of grazing has energetic costs that have been estimated to account for 25 to 50 % of cattle's daily energy requirements (Osuji 1974). Moreover, Havstad and Malechek (1982) estimated that daily mean energy expenditure of beef heifers grazing crested wheatgrass was 46 % greater than stall-fed heifers consuming similar forage.

Cool-season grasses are known to produce lower dry matter (DM) yield than warm-season species (Van Soest 1994). For this reason, under temperate conditions, digestible energy is the main factor that restricts performance of the grazing animal (Reid and Jung 1982). However, cool-season species are commonly thought to be of higher quality because of greater digestibility due to differences in proportions and arrangements of fibrous tissues (Akin 1986). Energy supplementation, balanced with other nutrients, is practiced in order to improve and/or maintain desired production levels of ruminants fed low to medium quality forages. However, supplementing energy often reduces forage intake and utilization in cattle (Paterson *et al.* 1994; Caton and Dhuyvetter 1997; Kunkle *et al.* 2000). In addition, depending on the type of carbohydrate, supplemental energy has variable effects on forage intake and performance of cattle grazing cool season species (Caton and Dhuyvetter 1997; Olson *et al.* 1999).

Grain supplementation (starch) has been shown to decrease forage dry matter (DM) intake in ruminants (Minson 1990). Jones *et al.* (1988) offered ground corn at 0.5 % of BW to growing dairy steers fed mature orchard grass hay, and reported that supplementation tended to reduce forage DM intake of steers compared to a non-supplemented group. In a study supplementing increasing levels (0, 0.2 and 0.4 % of BW) of corn starch to beef steers fed low-quality meadow hay, Sanson *et al.* (1990) found that supplementation quadratically decreased forage DM intake as well as DM digestibility. Pordomingo *et al.* (1991) supplemented beef steers grazing native rangeland during summer with increasing levels (0, 0.2, 0.4 and 0.6 % of BW) of corn grain and found that forage OM intake linearly decreased with level of corn inclusion. Boyles *et al.* (1998) offered three levels of a barley-based supplement (0.25, 0.5 and 0.75 % of BW) to beef steers fed smooth bromegrass hay, and observed that both low and medium levels of barley supplement had no effect on forage DM or OM intake. However, at the highest level (0.75 % of BW) of grain supplementation, both forage DM and OM intakes were significantly reduced compared to a non-supplemented control group of steers. These results agree with Horn and McCollum (1987), who concluded that supplementing energy up to 0.5 % of BW has no major effects on forage intake and utilization.

This detrimental effect of grain supplementation on forage DM intake and fibre digestibility can be attributed to an increase in fermentation rate and concentration of hydrogen ions (H^+) resulting in a reduction in ruminal pH to levels at which cellulolytic bacteria are affected as well as fibre digestion (Mould and Ørskov 1983; Russell and Wilson 1996).

Alternatively, degradable fibre supplementation has little or no effect on low quality forage intake compared to starch. Garces-Yepez *et al.* (1997) compared the performance and dietary intake of beef steers fed bermudagrass (*Cynodon dactylon*) hay and supplemented with two levels (25 and 50 % of the estimated TDN intake) of one of three supplements: corn-soybean meal (CSM); soybean hulls (SH); or wheat middlings (WM). When steers were supplemented at the low level, there was not difference among type of supplement on performance or hay DM intake. However, when steers were supplemented at the high level, both performance and forage DM intake were greater for SH and WM compared to the CSM supplemented group. Horn *et al.* (1995) evaluated the effects of high starch vs. high fibre energy supplements on stocker cattle grazing winter wheat pasture, and found that ADG was not affected by type of energy supplement. Grigsby *et al.* (1993) fed beef steers a diet consisting (DM basis) of 60 % low-quality bromegrass hay and 40 % of one of four combinations of soybean hull:ground corn (100:0 %, 66:33 %, 33:66 % and 0:100 %). Digestibility of both DM and OM were not affected by type of supplement; however, both NDF digestibility and ruminal pH tended to decrease linearly as the ground corn substituted the soybean hull in the concentrate.

In high forage diets, fat can be supplemented up to 6 % of the total DM intake without negative effects on animal performance, and benefits obtained from the energy of the dietary components can be maximized by supplementing fat up to 3 % of the total DM intake (Palmquist 1994; Hess *et al.* 2008). In general, fat supplementation has resulted in a decrease in fibre digestion and forage intake without negatively impacting performance. Pavan *et al.* (2007) supplemented 3 levels (0, 0.75 and 1.5 g kg^{-1} BW) of corn oil to beef steers grazing tall fescue (*Festuca arundinacea* Schreb.) pastures. It was observed that forage DM intake linearly decreased and ADG tended to be linearly increased by oil supplementation. Scholljegerdes and Kronberg (2010) conducted two experiments simultaneously to evaluate digestibility and performance of growing beef cattle grazing native range and supplemented with either corn-soybean meal or ground flaxseed. It was concluded that supplementation with ground flaxseed did not affect growth performance of animals even though OM and nitrogen digestibility were lower compared to corn-soybean meal supplementation.

2.3.2. Protein supplementation

Forage availability and digestibility, animal stage of production and/or requirements, other limiting nutrients and forage CP are factors that must be considered when designing protein supplementation programs. Ruminant response to supplemental protein is usually observed when the CP content of the basal diet is less than 6 to 8 % (Del Curto *et al.* 2000). This was confirmed by Karges *et al.* (1992) when performance of beef steers grazing summer native range with 10.8 and 9.4 % CP levels, was not beneficiated from supplemental rumen degradable protein (RDP) compared to an energy supplemented control group. In a review of 66 publications, Moore *et al.* (1999) concluded that the largest response to protein supplementation occurs when supplemental

CP intake was greater than 0.05 % of BW, and the response compared to non-supplemented groups was always positive when supplemental CP was greater than 0.1 % of BW.

The type of supplemental protein, RDP or ruminal undegradable protein (RUP), can also have an effect on forage intake. Olson *et al.* (1999) infused increasing levels of a degradable intake protein (DIP) source (sodium caseinate) to beef steers fed low-quality hay, and concluded that supplementing DIP increased OM intake and digestion. Similar findings were reported by Köster *et al.* (1996) when beef cows were supplemented increasing levels of degradable intake protein. Bandyk *et al.* (2001) infused degradable intake protein (sodium caseinate) in the rumen and post-ruminally to beef steers fed low-quality grass hay and concluded that compared to a non-supplemented group, both type of infusions of DIP improved forage utilization. However, comparing supplemented treatments, only ruminal infusion increased forage OM intake and digestibility.

Metabolizable protein (MP) requirements of growing cattle grazing mature pastures are rarely met by microbial protein synthetized from RDP; therefore, supplemental RUP will provide the MP needed for production purposes (Klopfenstein 1996; Reed *et al.* 2007). Anderson *et al.* (1988) supplemented beef steers grazing smooth bromegrass pasture with increasing levels of a blood meal and corn gluten blend (RUP source) and observed that animal performance increased as RUP level increased. It was also concluded that growing steers grazing smooth bromegrass pastures were deficient in metabolizable protein.

2.4. Supplementation frequency

Expenses associated with daily supplemental feeding can have a significant impact on both fixed and variable costs of beef cattle operations (Miller *et al.* 2001; Stalker *et al.* 2009). A less frequent supplementation strategy offers producers the opportunity to reduce the costs associated with this activity (Farmer *et al.* 2001; Loy *et al.* 2007; Cooke *et al.* 2008; Loy *et al.* 2008; Stalker *et al.* 2009; Drewnoski *et al.* 2011; Drewnoski and Poore 2011; Moriel *et al.* 2012).

2.4.1. Frequency of protein supplementation

Extensive research has been done on frequency of protein supplementation of grazing cattle fed low quality forage and most of the studies have concluded that there is little or no effect of decreasing the frequency of protein supplementation on forage intake and animal performance (Krehbiel *et al.* 1998; Huston *et al.* 1999). Farmer *et al.* (2001) offered a 43 % CP supplement at 0.36 % of BW at four different frequencies (daily, every 2^{nd}, every 3^{rd}, or every 5^{th} d) to beef steers fed low-quality tallgrass hay and concluded that supplementation frequency can be reduced to as infrequently as twice weekly without causing a negative effect on performance. Bohnert *et al.* (2002) supplemented beef steers fed low-quality meadow hay with RDP and RUP at 3 frequencies (daily, every 3^{rd}, or every 6^{th} d). It was observed that both supplemental RDP and RUP increased DM intake and N digestibility compared to a non-supplemented group, but frequency of supplementation did not affect DM intake or N digestibility.

2.4.2. Frequency of energy supplementation

In comparison to frequency of protein supplementation, there has been little research evaluating the effects of reducing the frequency of energy supplementation. In addition, the few studies that have been conducted tend to show a reduced performance of cattle fed low quality forages when energy supplements were fed less frequently compared to daily supplementation (Kunkle *et al.* 2000). Loy *et al.* (2008) offered two levels (low and high) of dry-rolled corn (DRC) at two frequencies (daily or every 2^{nd} d) to crossbred heifers fed bromegrass hay. It was observed that supplementing DRC on alternate days, at both levels, decreased hay DM intake and performance. Moriel *et al.* (2012) evaluated the effect of offering daily or on alternate days a soybean hulls-based supplement to beef heifers fed two different qualities (low and medium) of bermuda grass hay and concluding that DM intake of hay and reproductive development of beef heifers fed both low- and medium-quality forages were improved when low-starch energy supplements were offered daily instead of on alternate days. Drewnoski and Poore (2012) offered daily and on alternate days, a blend of soybean hulls and corn gluten meal (14.6 % CP; 50.2 % NDF; 10.3 % starch) to beef steers fed medium-quality tall fescue hay and observed a reduction in hay DM intake for the alternate compared to daily supplementation treatment.

Compared to starch and degradable fibre supplements, little research has been done looking at the effects of different frequencies of supplementation of fat based supplements for grazing beef cattle. A few studies have evaluated the effects of frequency of corn DDGS as an energy supplement due to its high fat levels. However, NDF and CP contents in corn DDGS are also significant. Stalker *et al.* (2009) evaluated the effect of different supplementation frequencies on performance and diet digestibility of steers fed low quality forage and supplemented with corn DDGS containing 10 % ether extract (DM basis). Hay and total DMI tended to decrease linearly when steers were supplemented every 2nd or 3rd day compared to daily supplementation. Also, supplementation frequency had a significant linear effect on DM and OM apparent digestibility which were reduced when the frequency of supplementation was reduced. Animal performance decreased significantly by reducing the frequency of DDGS supplementation from daily to every two days (ADG = 0.82 and 0.65 kg d^{-1}, respectively). Loy *et al.* (2007) also observed a decrease in hay and total DM intakes, and performance of beef heifers when corn DDGS was supplemented at a lower frequency.

2.5. By-product feeds

A by-product feed is a secondary product that can have value as an animal feed and is obtained during the harvesting or processing of a principal commodity (Grasser *et al.* 1995).

By-product feedstuffs are typically higher in fibre and lower in non-structural carbohydrates (NSC) than cereal grains. Supplementation of by-products to ruminants has been shown to have less of a negative impact on forage intake and digestibility compared to grain-based supplements (Hoover 1986; Bowman and Sanson 1996). In addition, some by-product feeds are high in CP content, especially the non-soluble fraction (RUP), as a consequence of the industrial processing applied during fermentation and/or extraction of either grain starch or oil (Boila and Ingalls 1994; Ham *et al.* 1994)

2.5.1. Canola screenings

Canola screenings are a by-product obtained during the cleaning process of canola seed and is one of the more widely available by-products in Western Canada (Darroch *et al.* 1990; Stanford *et al.* 2000). According to Beames *et al.* (1986),canola screenings are classified depending on CP and fat content as either fines (17-21 % CP; 15-25 % fat) or coarse screenings (10-16 % CP; 7-16 % fat).

In a digestibility trial, Stanford *et al.* (2000) observed that replacing total alfalfa (*Medicago sativa* L.) and 33 % of barley grain with canola screenings up to 45 % of total DM of the diet did not affect apparent nutrient (DM, OM, NDF and ADF) digestibility and nitrogen retention in Romanov lambs. Additionally, Stanford *et al.* (2000) evaluated 4 increasing levels of canola screenings in growing feedlot lamb diets and concluded that ADG linearly decreased as level of CS was increased, and DM intake was linearly and quadraticaly increased as level of canola screenings increased in the diet. In growing cattle, Pylot *et al.* (2000a) evaluated the inclusion of CS in the diet of feedlot steers, observing that animal performance was not affected when barley grain was replaced by up to 50 % canola screenings.

2.5.2. Dried distillers' grains

Stillage is a by-product obtained after grain fermentation for ethanol production and can be divided into solid and liquid fractions known as wet distillers' grains and thin stillage, respectively. Thin stillage water is evaporated and the resultant solubles are usually added back to distillers' grains. Finally, dried distillers' grains (DDG) or DDG with solubles (DDGS) are the result of a drying process applied to wet distillers' grains with or without solubles (Ojowi *et al.* 1997; Spiehs *et al.* 2002; Klopfenstein *et al.* 2008).

Corn and wheat-based DDGS are the main type of DDGS used for livestock feeding in North America. As a consequence of the fermentation process, both corn and wheat-based DDGS show negligible starch content but increased protein, fibre and fat levels (Klopfenstein *et al.* 2008; Nuez-Ortin and Yu 2009). However, nutrient composition can differ depending on the fermented grain source. Walter (2010) reported that, compared to corn, wheat DDGS have a higher CP (39.3 vs. 30.5 %), similar fibre (38.8 vs. 38.1 % NDF).and lower fat levels (5.4 vs. 13.6 %).

The nutrient profile of distillers' by-products makes them suitable as part of diets for growing cattle (Mustafa *et al.* 2000a). Ham *et al.* (1994) reported greater performance of growing calves supplemented with 3 levels (low, medium and high) of corn DDGS compared to a control group fed ground corn and urea; however, cattle had similar daily gains among the 3 supplemental levels of corn DDGS. Moreover, McKinnon and Walker (2008) showed that animal performance is not affected when wheat-based DDGS is included at either 25 or 50 %, replacing barley grain in backgrounding steer diets.

2.5.3. Grain screenings

Grain screenings are the by-product resulting from the process of cleaning grain for export or use in specialized markets within Canada. Grain screenings are divided into four classes based on its allowable content of parental material: either broken or shrunken kernels, hulls, weed seeds or dust (Canadian Grain Commission 1996). Marx *et al.* (2000) sampled 18 loads of grain screenings over 2 years and evaluated the nutrient composition and feeding value of grain screening pellets for ruminants. They concluded that grain screening pellets are a good source of degradable protein and carbohydrate for ruminants even though grain screenings had lower *in situ* degradation rates and lower total tract utilization of DM and gross energy compared to whole barley grain.

2.5.4. Oat hulls

Oat hulls are the by-product of the oat milling industry. The hull represents up to 25 % of the total weight of the oat grain (Crosbie *et al.* 1984). Similar to crop hull residues, oat hulls have a great potential as a feed for ruminants due to their structural carbohydrate content (Hsu *et al.* 1987; Garleb *et al.* 1991). The nutritive value for ruminants of hulls from the 10 most common varieties of oat grown in Western Canada was evaluated by Thompson *et al.* (2000), obtaining average values (min-max values) of 2.9 % CP (2.3-4.5 % CP), 85.3 % NDF (88.2-77.9 % NDF), 46.4 % ADF (42.5-49.6 % ADF) and 41.6 % IVDMD (33.1-68.2 % IVDMD). Furthermore, Thompson *et al.* (2002) used growing steers to evaluate the effect of replacing 50 % of barley silage with either untreated or ammoniated oat hulls. It was observed that when feeding untreated oat hulls, DM intake and animal performance were reduced compared to barley silage and ammoniated oat hulls but no difference was observed between the latter 2 treatments. Overall, it was concluded that ammoniation improves the feeding value of oat hulls and the cost of backgrounding programs can be reduced by feeding ammoniated oat hulls.

2.5.5. Pea hulls

Pea hulls (PH) are the by-product obtained from the cleaning of the mature pea seed consisting mainly of non-starch polysaccharides such as cellulose together with variable amounts of pectins and xylans, and small amounts of lignin, and represents between 9.0 and 14.0 % of the total weight of the pea seed (Kromann *et al.* 1977; Jimenez-Moreno *et al.* 2011).

2.5.6. Wheat middlings

Wheat middlings are the by-product of wheat milling. They are used in the feed industry in many blended supplements and are quite palatable when pelleted (Kunkle *et al.* 2000). Sunvold *et al.* (1991) reported that when beef steers fed a dormant tall grass hay and were supplemented with 2 levels of wheat middlings replacing a soybean meal and sorghum grain supplement, forage DMI and DM digestibility increased compared to a non-supplemented control group but were not affected by the type of supplement offered. According to Blasi *et al.* (1998), wheat middlings had 95 % the feeding value of corn-soybean meal blend for growing cattle fed *ad libitum* sorghum silage diets. Supplementing wheat middlings and corn-soybean meal gave similar performance when fed to growing cattle at 0.5 % of BW; but when fed at 1 % of BW, cattle fed wheat middlings supplements had 18 % (0.14 kg d^{-1}) higher gains (Garces-Yepez *et al.* 1997). ZoBell *et al.* (2003) evaluated the effect of replacing barley and corn grain with wheat middlings in growing and finishing steer diets and concluded that WM can be included in diets in both phases up to 50 % of dietary DM without negatively affecting animal performance.

2.6. Summary

Overall, stockpiling perennials is a cost effective and practical way of extending the grazing season, and crested wheatgrass is among the species that have shown potential for stockpiling in the Western Canadian prairies. However, beef cattle grazing stockpiled forages are generally deficient in nutrients for production, and under temperate conditions energy is the main limiting nutrient in cool-season forage species. Therefore, a strategic supplementation program can mitigate the nutrient deficiencies of cattle grazing stockpiled crested wheatgrass. Moreover, supplementation can be provided less frequently and using by-product feeds to reduce the cost of this practice.

The hypothesis of this study was that supplementing a by-product feed pellet that provides ruminal and post-ruminal energy at a targeted level and frequency can improve animal performance and increase productivity of growing beef cattle fed stockpiled forage.

Therefore, two grazing trials and one metabolism trial were conducted to determine the effects of source, frequency and level of supplementing digestible energy from by-product feeds on performance, forage intake, rumen fermentation and nutrient digestibility efficiency of growing beef cattle grazing stockpiled crested wheatgrass pastures.

3. EFFECT OF THE SOURCE OF RUMEN DEGRADABLE ENERGY SUPPLEMENTATION ON FORAGE INTAKE, PERFORMANCE, AND PRODUCTIVITY OF STEERS GRAZING STOCKPILED CRESTED WHEATGRASS (*Agropyron cristatum* L.).

3.1. Introduction

Grazing is the most cost-effective way of feeding ruminants and grazing management strategies such as extending the grazing season can reduce the cost of feeding beef cattle during the fall-winter season (Frame 2004). Stockpiling perennial forages is a practical and economical way to extend the grazing season that has proven to reduce winter feeding costs by up to 40 % (Poore *et al.* 2000; Baron *et al.* 2004). However, grazing cattle usually cannot meet their nutritional requirements due to limited energy and/or protein content of the pasture (Moore *et al.* 1999; DelCurto *et al.* 2000). Under temperate conditions, digestible energy is the most limiting nutrient (Reid and Jung 1982). In addition, when cattle are exposed to low-protein/high-fibrous forages as is the case for stockpiled pastures, the deficiency of digestible energy and/or protein for production is increased making supplementation a necessary practice.

Supplementation of energy and/or protein has been shown to improve performance of grazing cattle (Caton and Dhuyvetter 1997; Moore *et al.* 1999; DelCurto *et al.* 2000). However, protein supplementation has been less effective in cattle grazing cool season species; while supplemental energy, balanced for protein content has been shown to have a greater positive effect on performance (Galloway *et al.* 1991; Caton and Dhuyvetter 1997; Bohnert *et al.* 2011). In ruminants, digestible energy can be provided ruminally or post-ruminally. The source of rumen degradable energy can have various effects on intake and performance of cattle fed high-forage diets. Grain (starch) supplementation has been shown to improve performance; however, at the same time forage intake decreases (Caton and Dhuyvetter 1997; Olson *et al.* 1999). This has been attributed to a reduction in ruminal pH and forage digestibility (Mould and Orskov 1983). On the other hand, degradable fibre supplementation has been shown to improve performance of cattle fed low-quality forage with little or no effect on forage intake (Bowman and Sanson 1996; Kunkle *et al.* 2000).

The western Canadian prairies are dominated by the presence of cool season grass species such as crested wheatgrass (*Agropyron cristatum* L.). Crested wheatgrass is the most successfully established introduced grass in the western Canadian prairies (Rogler and Lorenz 1983) and has been shown to have potential for stockpiling (Baron *et al.* 2004). The main characteristic of crested wheatgrass is that it is high in palatability and nutritive value early in the growing season.Typically, nutritive value as well as palatability decreases after crested wheatgrass has reached its mature stage (Daugherty *et al.* 1982; Hart *et al.* 1983; Hoffman *et al.* 1993). Growing cattle grazing early season crested wheatgrass are able to maintain daily gains close to one kg. However, as crested wheatgrass matures, animal performance decreases as a consequence of decreasing forage quality (Daugherty *et al.* 1982; Ojowi *et al.* 1996). Research has shown that performance of cattle grazing mature crested wheatgrass was significantly improved when nutrient supplementation (thin stillage, DDGS, and barley) was practiced (Ojowi *et al.* 1996; Clark *et al.* 2009).

Western Canada is a large producer of cereal grain and oil seeds. The harvesting and industrial processing of these agricultural commodities result in a large amount of by-product feeds which have been shown to have an important nutritive value for feeding ruminants when offered individually. Inclusion of canola screenings at values up to 50 % in feedlot diets did not affect performance of feedlot steers (Pylot *et al.* 2000a). According to Mustafa *et al.* (2000b), the nutrient profile of by-products obtained from ethanol production makes them suitable for diets in growing cattle. Replacing up to 50 % of barley grain with wheat-based DDGS in feedlot diets did not affect performance of backgrounding steers (McKinnon and Walker 2008). Garces-Yepez *et al.* (1997) replaced barley and corn grain with wheat middlings, and observed no effect on performance when wheat middlings were included at levels up to 50 % in growing and finishing diets of beef steers. To date, little or no research has examined the effect of blending various types of western Canadian by-product feeds as supplements for grazing cattle.

The hypothesis of this study was that supplementation of by-product feeds can improve animal performance by providing rumen degradable energy either as starch or degradable fibre when offered at a targeted level.

The objectives of this study were to formulate using western Canadian by-product feeds as ingredients, two isonitrogenous and isocaloric pelleted supplements which differed in the type of rumen available energy (starch vs. digestible fibre), and to determine their effect on forage utilization and animal performance when offered to steers grazing stockpiled crested wheatgrass. The aim was to target a specific level of performance (1 kg d^{-1}) for growing beef steers grazing stockpiled crested wheatgrass pastures when pelleted by-product feed supplements were offered at 0.6 % of BW.

3.2. Materials & Methods

Guidelines for animal care (Canadian Council on Animal Care 1993) were followed at all times for the animals used in this study.

3.2.1. Study location

A grazing study was conducted during the summer/fall of 2011 at Termuende Research Ranch of the Western Beef Development Centre in Lanigan, Saskatchewan, Canada. A total of 16.2 ha of long established crested wheatgrass (*Agropyron cristatum* L.) with some smooth bromegrass (*Bromus inermis* L.) and Kentucky bluegrass (*Poa pratensis* L.) invasion in lower moist areas were divided into nine 1.8 ha paddocks. Pastures were fertilized with 50 kg ha^{-1} of urea at the beginning of the growing season and were not grazed until the start of the study. Soils at the study site are Oxbow black soil association on a medium textured sandy loam soil (Wright 1986).

3.2.2. Animal management and Treatments

Forty five crossbred yearling steers (BW±SD; 334±23.5 kg) grazed stockpiled crested wheatgrass pastures for 70 days (3 August to 12 October) in 2011. Steers were stratified by IBW and randomly assigned to 1 of 9 paddocks (5 steers/paddock). Each paddock was then randomly assigned to 1 of 3 replicated (n=3) supplementation strategies: (1) no supplement was offered (CON); (2) a low starch/high fibre pelleted supplement (LS/HF) offered at 0.6 % of BW; or (3) a high starch/low fibre pelleted supplement (HS/LF) offered at 0.6 % of BW. Pelleted supplements were formulated using various by-product feeds as ingredients (Appendix Table A.1) and using a least cost ration software program (General System Inc. Version 1.41). Pelleted supplements were formulated to differ in the proportions of rumen available energy (starch vs. degradable fibre), but to be iso-nitrogenous (16 % CP) and iso-caloric (3.6 Mcal kg^{-1} DE). Pelleted supplements were designed to meet or exceed nutritional requirements (NRC 2000) when offered at 0.6 % of BW to growing beef steers grazing mature crested wheatgrass and gaining 1 kg daily. A data base of thirty stockpiled crested wheatgrass samples collected during summer/fall of 2007 and 2008 from the same pastures grazed in this study (Appendix Table A.2) was used to estimate DM intake according to nutrient content of the forage. Forage DM intake was estimated to be 6.7 kg hd^{-1} d^{-1} using the CP_ADF equation (Appendix Equation A.1) for all-forage diets according to NRC (2000). Pellets were offered daily between 0800 and 0900. All groups had *ad libitum* access to a 2:1 mineral supplement (15.5 % Ca, 7 % P, 30 ppm Se, 20 ppm Co, 200 ppm I, 1500 ppm Cu, 5000 ppm Mn, 5000 ppm Zn, 1000 ppm Fe, 1.0 ppm F (max), 500 000 IU/kg Vitamin A (min), 50 000 IU/kg Vitamin D (min), 2500 IU/kg Vitamin E (min); Cargill Animal Nutrition, Manitoba, Canada) and cobalt-iodized salt (99.0 % NaCl (min), 39.0 % Na, 150 ppm I, 100 ppm Co; FeedRite Ltd., Humboldt, Saskatchewan, Canada) over the course of the trial. Water was supplied to each paddock in troughs.

The amount of pellet offered was recalculated every 14 days by estimating BW according to the model:

$$BW_e = BW_b + 7(ADG_{a-b})$$

where BW_e is the estimated body weight used for determination of supplement amount, BW_b is the body weight at the time where supplement amount changes, and ADG_{a-b} is the average daily gain during the 14 d period previous to supplement amount change.

3.2.3. Data collection

Forage utilization was estimated using the forage weight before and after grazing steers entered and exited each paddock (pre and post graze technique) as described by Cook and Stubbendieck (1986). On each paddock, thirty randomly distributed quadrats (0.25 m^2) were clipped to a 5 cm stubble height at the start and end of the grazing period. For each paddock, all thirty samples were composited in plastic bags at the start (available) and end (residual) of the grazing period. Five sub-samples were taken from each composite, placed in paper bags and dried in a forced air oven at 55°C for 72 h for DM determination. Weights of the dried available and residual forage samples were used to estimate forage utilization by steers according to the Herbage Disappearance Method (Jasmer and Holecheck 1984):

$$Forage\ utilization\ (\%) = \frac{DM\ available\ (g/0.25\ m^2) - DM\ residual\ (g/0.25\ m^2)}{DM\ available\ (g/0.25\ m^2)}$$

Forage intake was estimated using the following equation:

$$DMI(kg\ hd^{-1}\ d^{-1}) = \frac{DM\ available\ (kg) - DM\ residual\ (kg)}{n * \ d}$$

where *n* = the number of steers per paddock and *d* = the number of days the paddock was grazed.

Every 14 d throughout the course of the study, five randomly distributed quadrats (0.25 m^2) of forage were clipped from each paddock and immediately dried for DM determination. Pelleted supplements were also sampled every 14 d and immediately dried for DM determination. Forage and pelleted supplement DM were determined by drying samples at 55° C for 72 h in a forced air oven. After dried, forage samples were ground, composited by paddock, and stored until analysis to determine forage quality. At the end of the trial, samples from each pelleted supplement were composited and ground for analysis. All samples were gound to pass a 1-mm screen (Thomas-Wiley Laboratory Mill Model 4; Thomas Scientific, Swedesboro, NJ, USA).

Body weight (BW) was measured on 2 consecutive d at the start and end of trial, and every 14 d throughout the course of the trial. Subcutaneous body fat thickness (SCBF) was determined at the start and end of the trial by ultrasound measurement between the 12th and 13th rib using an Aloka SSD-500V ultrasound machine and an Aloka UST-5044 probe (3.5 MHz).

3.2.4. Laboratory analysis

All samples were analyzed in duplicate according to the Association of Official Analytical Chemists (AOAC; 2000). Samples were analyzed for moisture (analytical DM) by drying at 135° C for 2 h according to the procedure outlined by the Association of Official Analytical Chemists (method #930.15; AOAC 2000). Crude protein (CP) was determined by nitrogen combustion (method 990.03, AOAC 2000) using a Leco FP-528 Nitrogen Combustion Analyzer (Leco, MI, USA). Neutral (NDF) and acid (ADF) detergent fibre were analyzed using an ANKOM 2000 Fiber Analyzer (ANKOM Technology, Fairport, NY). The addition of heat stable α-amylase and sodium sulphite were implemented for NDF. Ash was determined by heating samples at 550° C during four h (method 942.05; AOAC 2000). Calcium and phosphorus were analyzed using the dry ashing procedure (methods 927.02 and 965.17; AOAC 2000, respectively). Calcium was determined using an atomic absorption spectrophotometer (Perkin-Elmer, Model 2380, CN, USA) while P concentration was read at 410 nm on a spectrometer (Pharmacia, LKB-Ultraspec® III, Stockholm, Sweden). Additionally, supplement was analyzed for soluble protein, starch, and fat (ether extract). Soluble protein was detrermined using the Borate-Phosphate procedure as detailed in Krishnamoorthy *et al*. (1982). Starch was analyzed using the method described by Hall (2008), including the use of acetate buffer and correction for free glucose, and ash (method 942.05; AOAC 2000). Ether extract was determined according to method 920.39 (AOAC 2000). Total digestible nutrients (TDN; % DM) and digestible energy (DE; Mcal kg^{-1} DM) were calculated for forage samples using the grass-legume Penn State equation (Appendix Equation A.2) based on ADF and for supplement samples using the Penn State equation (Appendix Equation A.3) for cereal grains (Adams 1995). Durability of the pellets was measured using a Holmen Pellet Tester (Holmen Chemical Ltd., Borregaard Group, Norsolk, UK), where 100 g sample of each pellet was conveyed pneumatically at 60 mbar in a closed circuit for 30 s, followed by sieving through a 2 mm sieve. Pellet durability index (PDI) was recorded as the proportion of the feed not passing through the sieve after treatment in the Holmen tester.

3.2.5. Statistical analysis

The Mixed procedure of SAS (Version 9.2; SAS Inst., Inc., Cary, NC) was used for all statistical analysis. Main effects of treatment on forage utilization, DM intake, BW (initial, final, and total gain), cumulative ADG and SCBF (initial and final) were analyzed as a completely randomized design using the Satterthwaite option to estimate denominator degrees of freedom. The statistical model was:

$$y_i = \mu + \tau_i + \varepsilon_i$$

where y_i is the dependent variable, μ is the overall mean, τ_i is the fixed effect of the ith treatment, and ε_i is the error term specific to the experimental unit (paddock) assigned to the ith treatment. Means were separated using Tukey’s method in SAS (Version 9.2; SAS Inst., Inc., Cary, NC). Differences were considered significant at $P < 0.05$.

The effects of treatment, time, and the treatment × time interaction were evaluated for forage quality (CP, ADF, NDF, Ca, P and DE), BW and ADG using a completely randomized design accounting for repeated measures. The statistical model included treatment, time, and the treatment × time interaction as fixed effects. The Satterthwaite option was used to estimate denominator degrees of freedom. Eight covariance structures were tested: simple, compound symmetry, first order autoregressive 1, first order ante-dependence, unstructured, heterogeneous compound symmetry, Toeplitz and heterogeneous autoregressive. The covariance structure with the lowest Akaike's and Bayesian information criterion (AIC and BIC) values was selected (Littell *et al.* 1998). Least square means were separated using the Tukey-Kramer's method in SAS (Version 9.2; SAS Inst., Inc., Cary, NC). Differences were considered significant at $P < 0.05$.

3.3. Results & Discussion

3.3.1. Supplement composition

The relative proportions of the by-product feeds used in pelleted supplement formulations and chemical composition of the pelleted supplements are given in Table 3.1. The oat and pea hull content (18 % each) constituted most of the fibre content in LS/HF, while fibre content in HS/LF was reduced by limiting oat hulls to 6 % and no pea hulls were added. The difference in starch content between supplements was due mainly to the difference in grain and pea screenings. Grain screening (35.9 % starch) content was 13.4% greater in HS/LF, while pea screenings (31.7 % starch) content was 28.4 % in HS/LF vs. no inclusion in the LS/HF. Wheat middling (61 % starch) content was 33.9 and 43.2 % in LS/HF and HS/LF respectively and was an important supplier of starch to the pellets. Canola screenings (42.8 % EE) contributed to the fat content in both supplements. Protein in the LS/HF pellet came mainly from DDGS (37.2 % CP), while canola and pea screenings contributed to most of the CP in the HS/LF pellet. Even though there were differences in CP sources, the soluble CP portion of the total CP was similar between LS/HF and HS/LF pellets (39.6 and 39.3 % respectively).

Table 3.1. Ingredient and nutrient composition of pelleted supplements.

	Supplement[z]	
Item[y]	LS/HF	HS/LF
Ingredient (% DM)		
Canola screenings	9.9	7.2
DDGS	8.9	-
Oat hulls	18.0	6.6
Grain screenings	1.1	14.5
Wheat middlings	33.9	43.2
Pea hulls	18.0	-
Pea screenings	-	28.4
Peas	10.2	-
Nutrient (% DM)		
Dry matter (%)	92.7	92.9
Crude Protein	18.1	18.2
Soluble protein (% CP)	39.6	39.3
Neutral detergent fibre	29.5	22.8
Acid detergent fibre	17.8	12.2
Starch	40.3	48.6
Fat	5.0	3.8
Ash	4.4	5.5
Calcium	0.21	0.20
Phosphorus	0.41	0.42
Total digestible nutrients	75.7	76.5
Digestible energy (Mcal kg^{-1} DM)	3.3	3.4

[z]LS/HF = low starch/high fibre pelleted supplement; HS/LF = high starch/low fibre pelleted supplement. [y]DDGS = dried distiller's grain with solubles.

Durability of both pellets was similar. Average PDI were 96 and 98 % for LS/HF and HS/LF, respectively. The PDI in the LS/HF pellet was expected to be less than that in HS/LF pellet due to less starch and greater fat content compared to HS/LF pellet. Starch content is positively correlated with PDI of pelleted feeds, while fat content has a negative effect on durability (Wood 1987; Thomas *et al.* 1998).

The LS/HF and HS/LF pelleted supplements were similar in CP (18.1 and 18.2 % CP respectively) and energy (3.3 and 3.4 Mcal kg^{-1} DM respectively) content, but differed somewhat to formulated values (16 % CP and 3.6 Mcal kg^{-1} DM). Also, supplements were formulated to differ by 10 % for starch and NDF content, and to be similar in fat content (6 %). Actual differences were 8.3 and 6.7 % for starch and NDF content respectively, while fat content differed by 1.2 % between supplements. The discrepancy between formulated and actual values, can be attributed to variability in nutrient composition of by-product feeds due to type of by-product, processing plant and method (Belyea *et al.* 1989; Spiehs *et al.* 2002; Ortin and Yu 2009). Moreover, Arosemena *et al.* (1995) after evaluating 51 samples from 9 different by-product feeds concluded that the variability in by-product composition is more evident when evaluated on a concentrate mix basis than on an individual feed basis.

Although the difference in NDF content between the two supplements was not as large as expected, the fibre content of the LS/HF pellet was expected to be more digestible compared to the HS/LF pellet. As indicated previously, a large portion of the fibrous fraction in the LS/HF pellet arose from pea hulls while the fibre in the HS/LF pellet came mainly from oat hulls. The digestibility of the fibre from pea hulls is greater compared to oat hulls (Titgemeyer *et al.* 1991).

Fat content of the two supplements was 5 and 3.8 % for LS/HF and HS/LF, respectively. Although supplements differed in fat content, the contribution of supplemental fat to total dietary

DM intake (Table 3.5) represents 1.0 and 0.8 % for LS/HF and HD/LF treatments, respectively. This slight difference is not likely to affect forage DM intake considering the negligible fat contribution from grasses (Harfoot and Hazlewood 1997), and the 6 to 7 % of total dietary intake that needs to be represented by fat in order to negatively affect forage intake in ruminants (Palmquist 1994; Hess *et al.* 2008).

3.3.2. Pasture quality

The nutrient composition of stockpiled crested wheatgrass pasture over the 70 d period of the study is presented in Table 3.2, and the nutrient composition across treatment and time (graze period) is presented in Table 3.3.

The average CP content of stockpiled crested wheatgrass pasture over the study was 8.2 %. According to Minson (1990) and Allison (1985) forage needs to be above 8 % CP in order not to affect DM intake. The average TDN content of the stockpiled crested wheatgrass pasture was 53.7 %, calculated using the Penn State equation (Appendix Equation A.1) based on ADF content (Adams 1995). Average CP and energy content in the stockpiled crested wheatgrass pasture were slightly below the requirements of cattle (NRC 2000), with CP and TDN being 9 and 12 % below the requirements for target production levels. This is consistent with energy being the most limiting nutrient in cool-season grass species (Reid and Jung 1982).

Table 3.2. Nutrient composition of stockpiled crested wheatgrass pasture.

Nutrient (% DM)	Mean ± SD[z]
Crude Protein	8.2 ± 1.2
Neutral detergent fibre	66.3 ± 3.7
Acid detergent fibre	42.2 ± 3.1
Ash	7.7 ± 0.8
Calcium	0.35 ± 0.07
Phosphorus	0.09 ± 0.02
Total digestible nutrients	53.7 ± 3.4
Digestible energy (Mcal kg^{-1} DM)	2.4 ± 0.1

[z]SD = standard deviation.

Table 3.3. Chemical composition of stockpiled crested wheatgrass pastures across treatments and time.

	Treatment (trt)[z]				Graze period (gp)							*P* value		
Item[x]	CON	LS/HF	HS/LF	SEM[y]	1	2	3	4	5	6	SEM[y]	trt	gp	trt×gp
Nutrient (% DM)														
Crude protein	7.9	8.0	8.5	0.20	10.0f	9.0e	8.2d	7.7c	7.3b	6.9a	0.15	0.15	<0.01	0.37
NDF	66.4	66.6	66.1	0.37	62.2a	63.3b	64.4c	66.2d	69.7e	72.3f	0.31	0.65	<0.01	0.20
ADF	42.3	42.2	42.0	0.24	38.1a	39.2b	40.9c	43.1d	45.2e	46.6f	0.21	0.57	<0.01	0.71
Calcium	0.37	0.32	0.34	0.031	0.40d	0.39d	0.36c	0.31b	0.31b	0.30a	0.019	0.55	<0.01	0.15
Phosphorus	0.09	0.09	0.09	0.005	0.12d	0.10c	0.09b	0.09b	0.07a	0.07a	0.004	0.80	<0.01	0.88
DE (Mcal kg^{-1})	2.4	2.4	2.4	0.01	2.6f	2.5e	2.4d	2.3c	2.2b	2.2a	0.01	0.57	<0.01	0.96

[z]CON = no supplement offered; LS/HF = low starch/high fibre pelleted supplement offered at 0.6 % of BW; HS/LF = high starch/low fibre pelleted supplement offered at 0.6 % of BW. [y]SEM = pooled standard error of mean. Least square means with different letters in the same row are different (P < 0.05) using Tukey-Kramer's method. [x]NDF = neutral detergent fibre; ADF = acid detergent fibre; DE = digestible energy.

The chemical composition of the stockpiled forage was not different ($P \geq 0.15$) among treatments. However, time negatively affected ($P < 0.01$) quality of forage for all variables. Crude protein decreased by 3.1 % while both NDF and ADF increased by 10.1 and 8.5 % respectively (Table 3.3). As expected, DE content of stockpiled crested wheatgrass pasture decreased 0.4 Mcal kg^{-1} during the study due to the increase in ADF content. This negative effect of time on forage quality has been documented for crested wheatgrass (Glover *et al.* 2004; Memmot *et al.* 2011). As the season progresses and forage advances into the dormant stage, its nutritive value decreases. Also, negative effects of time on forage digestibility have been reported for stockpiled forages (Beck *et al.* 2006) and for stockpiled crested wheatgrass (Baron *et al.* 2004).

3.3.3. Forage utilization and intake

Results for available and residual forage, as well as forage utilization over the 70 d of grazing are presented in Table 3.4. Results for estimated forage DM intake across treatments are shown in Table 3.5. Forage availability averaged 22.0 kg of DM hd^{-1} d^{-1} across treatments (P = 0.96) at the start of the trial. This is more than double the amount (10.0 kg of DM hd^{-1} d^{-1}) required for a 380 kg steer to gain 1 kg d^{-1} (NRC 2000). Available and residual forage were not different (P = 0.89 and P = 0.45 respectively) across treatments. Consequently, no difference (P = 0.50) was observed for forage utilization among treatments. Similar findings were obtained by Poore *et al.* (2006) who found no difference ($P > 0.20$) in forage utilization for beef heifers grazing stockpiled tall fescue forage with or without supplementation.

Table 3.4. Effect of source of rumen degradable energy supplementation on forage utilization of steers grazing stockpiled crested wheatgrass pastures.

	Treatment[z]				
Item	CON	LS/HF	HS/LF	SEM[y]	*P* value
Dry matter (%)					
Initial	45.7	46.4	45.0	2.04	0.89
Final	75.2	80.5	75.2	3.77	0.56
Available forage (kg DM ha^{-1})	4245.9	4361.9	4211.3	381.81	0.96
Residual forage (kg DM ha^{-1})	1092.3	1095.4	1181.3	52.90	0.45
Forage utilization (%)	74.1	74.7	71.6	1.87	0.50

[z]CON = no supplement offered; LS/HF = low starch/high fibre pelleted supplement offered at 0.6 % of BW; HS/LF = high starch/low fibre pelleted supplement offered at 0.6 % of BW. [y]SEM = standard error of mean.

Table 3.5. Effect of source of rumen degradable energy supplementation on estimated forage and total dry matter intake of steers grazing stockpiled crested wheatgrass pastures.

	Treatment[z]				
Item	CON	LS/HF	HS/LF	SEM[y]	*P* value
Dry matter intake (kg hd^{-1} d^{-1})					
Supplement	-	2.2	2.2	-	-
Forage	9.0	9.3	8.7	1.01	0.90
Total	9.0	11.6	10.9	1.01	0.26
Dry matter intake (% of BW)					
Supplement	-	0.6	0.6	-	-
Forage	2.4	2.4	2.2	0.25	0.82
Total	2.4	3.0	2.8	0.25	0.33

[z]CON = no supplement offered; LS/HF = low starch/high fibre pelleted supplement offered at 0.6 % of BW; HS/LF = high starch/low fibre pelleted supplement offered at 0.6 % of BW. [y]SEM = standard error of mean.

The estimated forage DM intake for CON (9.0 kg hd^{-1} d^{-1}) was higher than the DM intake estimated for supplement formulation (6.7 kg hd^{-1} d^{-1}) and calculated from the CP_ADF equation (Appendix Equation A.1) for all-forage diets (NRC 2000). This difference in estimated forage DM intake can be attributed to the fact that DM intake estimated using the CP_ADF equation showed a moderate correlation coefficient ($r^2 = 0.475$), and under-predicted (-9.7 % bias) when regressing actual vs. predicted DM intake in a data set (n = 38) for growing beef cattle (NRC 2000). In contrast, using the least square means for BW and performance (ADG) for CON presented in Table 3.6 and the equation (Appendix Equation A.4) for estimating forage intake from the growth of beef cattle by Minson and McDonald (1987), the estimated forage DM intake is 8.8 kg hd^{-1} d^{-1}. This is similar to the 9.0 kg hd^{-1} d^{-1} actual observed for the CON group.

No difference ($P \geq 0.82$) among treatments was observed for estimated forage DM intake, expressed either as kg hd^{-1} d^{-1} or as % of BW. The lack of negative effect on forage DM due to supplementation can be attributed to the level of supplemental TDN intake, and the N content in stockpiled crested wheatgrass pasture. In a review of 66 publications, Moore *et al.* (1999) suggested that supplementation decreased forage intake when supplemental TDN intake was greater than 0.7 % of BW, and forage TDN:CP ratio was less than 7. A value which they indicated was an adequate N content in forage. In this study, supplemental TDN intake was on average 0.46 % of BW, and the TDN:CP ratio of stockpiled crested wheatgrass pasture was 6.5 which is similar to the adequate N content suggested by Moore *et al.* (1999).

Moreover, in addition to the adequacy of dietary N and/or CP, the soluble fraction of the total CP (DIP) in the diet needs to be considered in order to explain the effect of supplementation on forage DM intake. Olson *et al.* (1999) infused, via ruminal fistulae, increasing levels of DIP (Na-caseinate) to beef steers fed low-quality tallgrass hay and supplemented 3 levels (0, 0.15, and 0.3 % of BW) of corn starch. It was found that providing increasing levels of DIP linearly increased ($P < 0.01$) forage DM intake at each starch level. In this study, both LS/HF and HS/LF provided adequate and similar levels of CP (18.1 and 18.2 % respectively), and the soluble fractions of the CP were also adequate and equal between supplements (39.6 and 39.3 % of total CP as soluble protein for LS/HF and HS/LF, respectively).

3.3.4. Animal performance

Results for the main effect of treatment, main effect of time, and their interaction are shown in Table 3.6. The least square means across the entire grazing period, obtained from repeated measures analysis show that BW and cumulative ADG were improved ($P < 0.05$) by supplementation (LS/HF and HS/LF) compared to no supplementation (CON). No differences ($P > 0.05$) were found for BW and cumulative ADG between LS/HF (391.1 kg and 1.7 kg d^{-1}) and HS/LF (394.6 kg and 1.8 kg d^{-1}) treatments. Although the average animal performance across treatments was positive during the grazing period, time negatively affected the rate at which the steers grew. Average daily gain decreased ($P < 0.05$) for every time point which can be attributed to the decrease in forage quality previously discussed. It is widely documented that as crested wheatgrass and forages in general mature and reach dormancy, forage CP content and digestibility decrease with a concurrent increase in fibre leading to diminished animal performance (Wallace *et al.* 1963; Park *et al.* 1994; Jung and Allen 1995; Johnson *et al.* 1998). Ojowi *et al.* (1996) reported that cumulative ADG decreased as season advanced for steers grazing crested wheatgrass pastures without supplementation.

A treatment × time interaction ($P < 0.01$) on BW was observed (Figure 3.1). A similar tendency in growth of steers grazing crested wheatgrass during summer-fall was shown by Karn *et al.* (1999). However, two different growing rates can be distinguished in Figure 3.1.

Table 3.6. Effects of source of rumen degradable energy supplementation (trt), time (d) and their interaction (trt×d) on performance of steers grazing stockpiled crested wheatgrass pastures.

	Treatment[z]				Day							*P* value		
Item[x]	CON	LS/HF	HS/LF	SEM[y]	0	14	28	42	56	70	SEM[y]	trt	d	trt×d
BW (kg)	377.5a	391.1b	394.6b	2.04	334.0a	363.2b	382.9c	401.8d	419.0e	425.3f	1.57	<0.01	<0.01	<0.01
ADG (kg d^{-1})	1.4a	1.7b	1.8b	0.07	-	2.1d	1.7c	1.6c	1.5b	1.3a	0.04	<0.01	<0.01	0.43

[z]CON = no supplement offered; LS/HF = low starch/high fibre pelleted supplement offered at 0.6 % of BW; HS/LF = high starch/low fibre pelleted supplement offered at 0.6 % of BW. [y]SEM = pooled standard error of mean. Least square means with different letters in the same row are different ($P < 0.05$) using Tukey-Kramer's method. [x]BW = body weight; ADG = cumulative average daily gain.

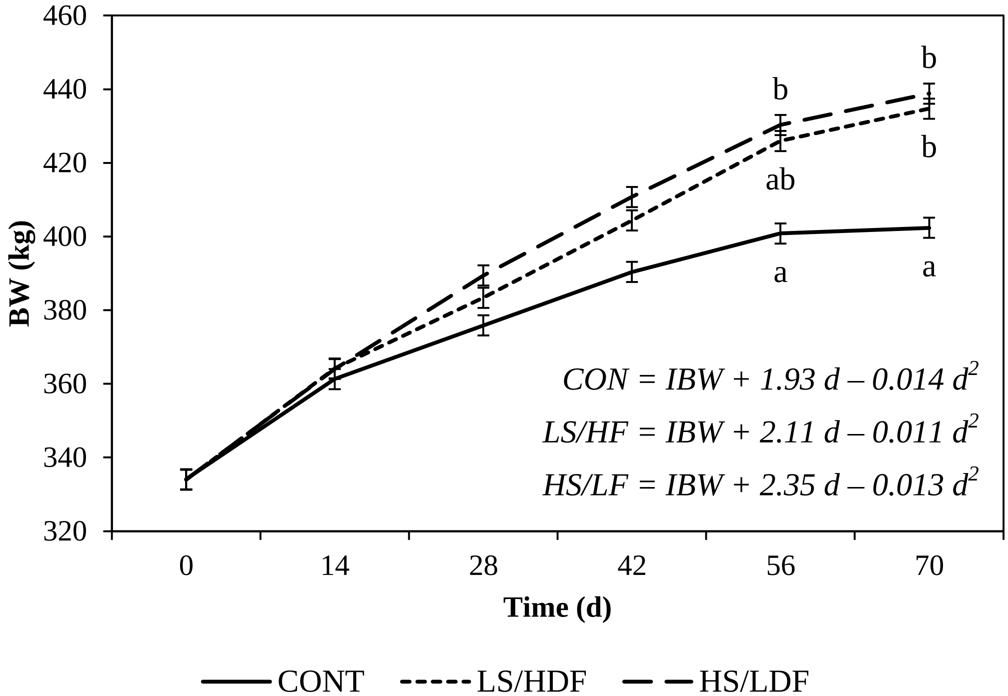

Figure 3.1. Effect of treatment and time interaction on body weight (LSM ± SE) of steers grazing stockpiled crested wheatgrass pastures.

When modeling time (d) as a regression variable for all treatments, BW had both positive linear ($P < 0.01$) and negative quadratic ($P < 0.01$) components for all treatments. However, the magnitude of the positive linear components was numerically higher for supplemented treatments compared to the non-supplemented treatment, while the negative quadratic components were similar among treatments. According to this analysis, BW linearly increased at 1.9, 2.1 and 2.3 kg d^{-1} for CON, LS/HF, and HS/LF, respectively. In opposition, the rate of BW growth quadratically decreased at 0.014, 0.011 and 0.013 kg d^{-1} for CON, LS/HF, and HS/LF, respectively.

Solving the equations to find the time (d) at which maximum weight would be reached, it was found that CON, LS/HF, and HS/LF would reach maximum weight at 68, 97, and 90 d, respectively. This indicates that supplemented treatments would have kept growing beyond the 70 d that trial lasted, while steers in the non-supplemented treatment stopped growing before the end of the grazing period. The BW obtained at the maximum point of each equation was 400.2, 437.1 and 439.6 kg for CON, LS/HF and HS/LF, respectively.

Results for cumulative animal performance over the 70 d of grazing period are shown in Table 3.7. Animal performance was greater than expected and increased with supplementation. The non-supplemented treatment (CON) had the lowest ($P < 0.05$) animal performance (final BW, gain, and ADG). Cumulative ADG observed for CON (1.0 kg d^{-1}) was similar to that (0.97 kg d^{-1}) reported by Karn *et al.* (1999) for beef steers grazing crested wheatgrass throughout the summer in North Dakota. However, actual cumulative ADG is higher compared to that reported (0.91 kg d^{-1}) by Ojowi *et al.* (1996) for yearling steers grazing the same pastures utilized in this study during spring and early summer (12 % CP and 62 % NDF).

On average, supplementation increased ($P < 0.01$) total gain and cumulative ADG by 51 and 45 % respectively. No differences ($P > 0.05$) in final BW, total gain, and ADG were observed between supplemented treatments. These results agree with Horn *et al.* (1995) and Garces-Yepez (1997) who found no difference in performance of beef steers grazing wheat pastures or bermuda grass and offered high-starch or high-fibre supplements, but did observe an effect of supplementation compared to no supplementation.

Table 3.7. Effects of source of rumen degradable energy supplementation on performance of steers grazing stockpiled crested wheatgrass pastures.

Item	Treatment[z] CON	LS/HF	HS/LF	SEM[y]	*P* value
Body weight (kg)					
Initial	334.1	334.0	334.0	0.78	0.99
Final	402.4a	434.7b	438.8b	4.48	< 0.01
Change	68.3a	100.8b	104.8b	4.57	< 0.01
ADG (kg d^{-1})					
70 days	1.0a	1.4b	1.5b	0.07	< 0.01
Rib fat thickness (mm)					
Initial	2.1	2.4	2.1	0.13	0.31
Final	2.5	2.9	3.1	0.20	0.16
Change	0.3	0.5	0.9	0.24	0.27

[z]CON = no supplement offered; LS/HF = low starch/high fibre pelleted supplement offered at 0.6 % of BW; HS/LF = high starch/low fibre pelleted supplement offered at 0.6 % of BW. [y]SEM = standard error of mean.

Contrary to documented negative effects of starch supplementation on forage DM intake and performance (Chase and Hibberd 1987; Pordomingo *et al.* 1991), supplementing the high starch pellet (HS/LF) in this study did not affect forage DM intake when compared to no supplementation (CON) and supplementation with the low starch pellet (LS/HF). Moreover, HS/LF and LS/HF supplementation equally improved cattle performance compared to CON. This can be explained by three factors. First, the supplementation level (0.6 % of BW) was slightly over the supplemental energy level (0.5 % of BW) that, according to Horn and McCollum (1987) can be fed without significant negative effects on forage intake. However, Garces-Yepez *et al.* (1997) observed similar performance on growing cattle offered wheat middlings and corn-soybean meal supplements at 0.5 % of BW, but those offered wheat middlings gained 0.14 kg d^{-1} more when supplementation level was increased to 1 % of BW. Second, it has been well documented that starch supplementation decreases ruminal pH resulting in reduced growth of cellulolytic bacteria and fibre digestibility (Mould *et al.* 1983; Mould and Ørskov 1983). However, Grigsby *et al.* (1993) reported that ruminal pH slightly decreased from 6.3 to 6.2 when beef steers fed low-quality grass hay went from 100% soybean hulls to 100% ground corn supplementation, without affecting DM and OM digestibility. Finally, as indicated previously for estimated forage DM intake, providing an energy supplement (starch vs. fibre) with an adequate content of DIP has been shown to have no negative effect on forage intake and also to improve performance regardless of the energy source (Bodine *et al.* 2001; Bodine and Purvis 2003). Supplementation and type of supplement did not affect ($P \geq 0.16$) final or change in SCBF.

This high overall performance of cattle on stockpiled crested wheatgrass pasture can be attributed to various factors. First, compensatory gain was observed during the first 14 d of the study when ADG was 2.1 kg d^{-1} and was not different ($P > 0.05$) among treatments. Compensatory gain (or growth) as defined by Sainz *et al.* (1995) is the more rapid and efficient growth of animals following a period of restricted feeding. The ADG for CON from the start of trial until 14 d of the grazing period was 1.9 kg d^{-1}, while the ADG from 14 d until the end of trial was 0.7 kg d^{-1} (data shown in Appendix Figure A.1). In addition, the initial high CP content of the stockpiled crested wheatgrass pasture improved performance of cattle. Analyzing ADG in the CON treatment by period, it was observed that cattle maintained gains over 1.0 kg d^{-1} from 14 d until 42 d of the study (1.04 kg d^{-1}) when the average CP of forage was 8.3 %. After 42 d, ADG decreased 59 % to 0.43 kg d^{-1} until the end of study, while average CP of forage for the last 2 grazing periods decreased to 7.3 %. Finally, energy content of forage was deficient from the start of the trial and this deficiency increased as grazing period progressed. However, the high amounts of available forage and selective grazing could have allowed cattle to increase their energy intake. Forage samples collected from grazing ruminants with esophageal cannulas indicate superior quality and digestibility compared to clipped samples of the same pasture forage (Weir and Torell 1959; Ellis 1978).

Performance of supplemented cattle was greater than the target level (1.0 kg d^{-1}). The reason for this can be attributed to the fact that forage DM intake was greater than estimated for supplement formulations; an thus, total CP and energy intakes exceeded that required for 1.0 kg of daily gain. Based on forage quality (Table 3.2), estimated forage DM intake and supplement intake (Table 3.4) for LS/HF and HD/LF treatments, average total CP and DE intakes were 1.14 kg $^{-1}$ and 29 Mcal d^{-1} (65.8 % TDN) for both supplemented treatments. These values are similar to the 1.06 kg d^{-1} of CP and 70 % TDN required for a 381 kg steer to gain 1.38 kg per day according to NRC (2000).

3.3.5. Economic analysis

Partial economic analysis of this study is presented in Table 3.8. Economic analysis included variable costs relative to feed and yardage costs associated with supplement strategy, equipment use (fuel included), and labour. Fixed costs such as cost of grazing and depreciation were considered constant across treatments and not included in this analysis.

Sufficient quantities of LS/HF and HS/LF supplements were secured for the study in July 2011. Both pelleted supplements were obtained from West Central Pelleting (Wilkie, Saskatchewan, Canada) and priced at $173 and $166 per tonne (July 2011) for LS/HF and HS/LF, respectively (Dean Skinner, personal communication). Mineral and salt were purchased from FeedRite Ltd. (Humboldt, Saskatchewan, Canada) and priced at $31.50 per 25 kg and $5.25 per block in 2011. Steers had *ad libitum* access to mineral and salt supplements, and amounts offered were recorded for each paddock. Labour was valued at $15.00 per hour. Machinery and equipment rates were valued $36.00 per hour (SMA 2012). Cost estimates for labour and truck usage were based on the assumption of 30 minutes to feed 150 steers and additional 15 minutes per day to check steers. Total costs were calculated on a daily basis per head ($\$ hd^{-1} d^{-1}$) and divided by total gain to generate a cost of gain ($\$ kg^{-1}$).

The revenue as $\$ kg^{-1}$ was calculated using the overall five year average (2007-2011) for feeder steers (Saskatchewan Ministry of Agriculture), and adjusted according to the difference between the average final BW of each treatment and a 408 kg feeder steer. Net profits were calculated and reported as profit per kg of gain ($\$ kg^{-1}$ of gain), and according to total gain over 70 d per head ($\$ hd^{-1}$).

Table 3.8. Economics of supplementing beef steers grazing stockpiled crested wheatgrass pasture

	Treatment[z]		
Item	CON	LS/HF	HS/LF
Feed costs (\$ hd^{-1} d^{-1})			
Supplement	-	0.42	0.40
Salt/Mineral	0.13	0.12	0.10
Total	0.13	0.54	0.50
Yardage costs (\$ hd^{-1} d^{-1})			
Machinery	-	0.12	0.12
Labour	0.03	0.08	0.08
Total	0.03	0.20	0.20
Total production cost (\$ hd^{-1} d^{-1})	0.16	0.74	0.70
Total cost of gain (\$ kg^{-1})	0.16	0.51	0.47
Revenue (\$ kg^{-1} of gain)	2.11	2.09	2.09
Net profit (\$ kg^{-1})	1.95	1.58	1.62
Net profit (\$ hd^{-1})	132.98	159.72	170.14

[z]CON = no supplement offered; LS/HF = low starch/high fibre pelleted supplement offered at 0.6 % of BW; HS/LF = high starch/low fibre pelleted supplement offered at 0.6 % of BW.

Activities associated with supplementation increased the costs of both supplemented treatments. Average production cost and cost of gain between LS/HF and HS/LF (\$0.72 hd^{-1} d^{-1} and \$0.49 kg^{-1} of gain) were 450 % and 300 % higher compared to costs for CON (\$0.16). Of the two supplemented treatments, production cost and cost of gain were 5.7 and 8.5 % lowest for the HS/LF treatment. This difference between the two supplemented treatments is mainly due to higher gain and lower cost of the pelleted supplement for HS/LF compared to LS/HF.

Despite the increased costs of production and gain, supplemented treatments had higher net profits compared to CON. Average profit expressed as \$ kg^{-1} of gain and \$ hd^{-1} between LS/HF and HS/LF were 82 and 24 % higher compared to CON. Of the two supplemented treatments, HS/LF had \$0.04 kg^{-1} gain and \$10.42 hd^{-1} more profit than the LS/HF treatment.

Since there was no difference ($P > 0.05$) in animal performance between steers supplemented with either LS/HF and HS/LF pellet, producers may decide which pelleted supplement to feed based solely on the current market cost of the supplement.

3.3.6. Beef production

Beef production analysis of the three grazing systems is presented in Table 3.9. The beef production of the system, in terms of kg and \$ produced per land unit on a daily basis, was higher for supplemented treatments compared to CON. On average, supplementation increased beef production by 1.4 kg ha^{-1} d^{-1} and \$2.8 ha^{-1} d^{-1}.

Table 3.9. Beef production of supplementing beef steers grazing stockpiled crested wheatgrass pastures

	Treatment[z]		
Item	CON	LS/HF	HS/LF
Beef production (kg ha^{-1} d^{-1})	2.7	4.0	4.2
Beef production ($ ha^{-1} d^{-1})	5.72	8.36	8.69

[z]CON = no supplement offered; LS/HF = low starch/high fibre pelleted supplement offered at 0.6 % of BW; HS/LF = high starch/low fibre pelleted supplement offered at 0.6 % of BW.

3.4. Conclusions

Pasture utilization and intake of cattle grazing stockpiled crested wheatgrass were not affected by supplementation of rumen degradable energy or the type of energy source. However, as the quality of the stockpiled forage decreased, steer performance was improved by supplementing digestible energy. The type of supplemental rumen available energy equally improved animal performance. Even though costs were increased for the supplementation treatments, final profit and total productivity were enhanced.

4. EFFECT OF FREQUENCY AND LEVEL OF ENERGY SUPPLEMENTATION ON FORAGE INTAKE, PERFORMANCE, AND PRODUCTIVITY OF STEERS GRAZING STOCKPILED CRESTED WHEATGRASS (*Agropyron cristatum* L.).

4.1. Introduction

Forages are deficient in energy and/or protein content required for efficient production of grazing cattle. Therefore, supplementation of forage fed cattle is an effective way of providing an additional source of the deficient nutrient in order to meet the animal's nutritional requirements for production (Holecheck and Carlton 1986; Kunkle *et al.* 2000). Both energy and protein have been shown to improve or maintain performance of grazing beef cattle (Caton and Dhuyvetter 1997; Moore *et al.* 1999; DelCurto *et al.* 2000). However, under temperate conditions, digestible energy is the most limiting nutrient (Reid and Jung 1982) and supplemental energy, balanced for protein content has been shown to have a positive effect on performance of growing cattle fed cool season forages (Galloway *et al.* 1991; Caton and Dhuyvetter 1997; Bohnert *et al.* 2011).

Supplementation practices bring additional cost to beef cattle systems, especially to those based on cattle grazing rangeland. These include the cost of supplement and the cost of delivering supplement every day. The former can be reduced through using by-product feeds which are not competitive with human feeding but are a good source of available nutrients for ruminants such as grain screenings and dried distillers' grain from ethanol production (Kunkle *et al.* 1995). Reducing the frequency of supplementation (i.e. every 2nd or 3rd day) can also reduce the cost of supplementation relative to daily supplement delivery (Cooke *et al.* 2008; Stalker *et al.* 2009; Moriel *et al.* 2012).

Reducing the frequency of supplemental protein feeding (as low as twice per week) has been shown to have little or no effect on animal performance and forage intake (Krehbiel *et al.* 1998; Huston *et al.* 1999; Bohnert *et al.* 2002). In contrast, reducing the frequency of providing energy supplementation has been shown to reduce both forage intake and cattle performance. Chase and Hibberd (1989) supplemented 2 levels of ground corn daily or on alternate days to beef cows and heifers fed low-quality grass hay, and concluded that corn supplementation on alternate days reduced the efficiency of nutrient utilization. Loy *et al.* (2008) offered growing heifers fed grass hay a supplement containing either dry-rolled corn or dry-rolled corn with corn gluten meal at two levels (0.21 and 0.81 % of BW) with varying frequencies of supplementation; daily or 3 times per week. They reported that decreasing supplementation frequency decreased ($P < 0.01$) hay DM intake (reduced by 13 %) and ADG (reduced by 10 %). Drewnoski *et al.* (2011) offered a blend of soybean hulls with corn gluten meal to growing steers fed medium-quality tall fescue hay either daily or 3 times/week and found that hay DM intake decreased ($P < 0.05$) by 0.8 kg d^{-1} when steers were supplemented on alternate days.

The negative effects of reducing the frequency of energy supplementation can be attributed to disturbed rumen fermentation, a diet substitution effect and partial consumption of the supplement (Drewnoski *et al.* 2011; Kunkle *et al.* 2000). The previously mentioned disturbances may also be impacted by the quantity of supplementation as studies comparing alternative day supplementation have increased the amount offered on the day of supplementation in order to balance the quantity of supplement offered on a weekly basis relative to daily supplementation programs. To date, no research has attempted to reduce the negative impact of alternate day supplementation by reducing the quantity of supplemental energy offered to a level below that which would be consumed on a daily basis over a 7 d period.

Therefore, the hypothesis of this study is that the negative impact of alternate day energy supplementation on animal performance can be mitigated by reducing the amount of supplement offered by 25 % on alternate days relative to those fed twice the daily amount on alternate days.

The objectives of this study were to determine the effects of offering a pelleted supplement, formulated to provide rumen (starch and degradable fibre) and post-rumen (fat) digestible energy, on forage intake and animal performance when offered daily or on alternate days at two different levels (1.5 and 2 × the daily amount) to steers grazing stockpiled pastures. The aim was to target a specific level of performance by optimizing energy use ruminally and postruminally.

4.2. Materials & Methods

Guidelines for animal care (Canadian Council on Animal Care 1993) were followed at all times for all animals used in this study.

4.2.1. Study location

A grazing study was conducted during the summer-fall of 2012 at Termuende Research Ranch of the Western Beef Development Centre in Lanigan, Saskatchewan, Canada. A total of 16.2 ha of long established crested wheatgrass (*Agropyron cristatum* L.), with some smooth bromegrass (*Bromus inermis* L.) and Kentucky bluegrass (*Poa pratensis* L.) invasion in lower moist areas, were divided into nine 1.8 ha paddocks. Pastures were fertilized with 50 kg ha^{-1} of urea at the beginning of the growing season and were not grazed until the start of the study. Soils at the study site are Oxbow black soil association on a medium textured sandy loam soil (Wright 1986).

4.2.2. Animal management and treatments

Forty five crossbred yearling steers (BW±SD; 358±17.7 kg) grazed stockpiled crested wheatgrass pastures for 70 days (1 August to 10 October) in 2012. Steers were stratified by IBW, randomly assigned to 1 of 9 paddocks (5 steers/paddock), and each paddock was randomly assigned to 1 of 3 replicated (n=3) supplementation strategies: (1) supplement offered daily (DLY) at 0.6 % of BW; (2) low alternate (LA) where supplement was offered on alternate days at 0.9 % of BW; and (3) high alternate (HA) where supplement was offered on alternate days at 1.2 % of BW (HA). Data observed in the 2011 study for forage nutrient composition and forage DM intake of supplemented treatments (Tables 3.2 and 3.5), were used for supplement formulation. Also, based on results observed in 2011, pelleted supplement was formulated to provide equal amounts of rumen available energy (starch and degradable fibre), and to provide a greater amount of fat compared to 2011 supplements. The pelleted supplement was formulated using various by-product feeds as ingredients and using a least cost ration software program (General System Inc. Version 1.41). The pelleted supplement was formulated to meet or exceed nutritional requirements (NRC 2000) of growing beef steers grazing mature crested wheatgrass and gaining 1 kg daily when offered at 0.6 % of BW of the supplement. The pelleted supplement was offered between 0800 and 0900 h. All groups had *ad libitum* access to a 2:1 mineral supplement (15.5 % Ca, 7 % P, 30 ppm Se, 20 ppm Co, 200 ppm I, 1500 ppm Cu, 5000 ppm Mn, 5000 ppm Zn, 1000 ppm Fe, 1.0 ppm F (max), 500 000 IU/kg Vitamin A (min), 50 000 IU/kg Vitamin D (min), 2500 IU/kg Vitamin E (min); Cargill Animal Nutrition, Manitoba, Canada) and cobalt-iodized salt (99.0 % NaCl (min), 39.0 % Na, 150 ppm I, 100 ppm Co; FeedRite Ltd., Humboldt, Saskatchewan, Canada) over the course of the trial. Water was supplied to each paddock in troughs.

The amount of pellet offered was recalculated every 14 days by estimating BW according to the following model:

$$BW_e = BW_b + 7(ADG_{a-b})$$

where BW_e is the estimated body weight used for determination of supplement amount, BW_b is the body weight at the time where supplement amount changes, and $ADG_{a\text{-}b}$ is the average daily gain during the 14 day period previous to supplement amount change.

4.2.3. Data collection

Forage utilization was estimated using the forage weight before and after grazing steers entered and exited each paddock (pre and post graze technique) as described by Cook and Stubbendieck (1986). On each paddock, thirty randomly distributed quadrats (0.25 m^2) were clipped to a 5 cm stubble height at the start and end of the grazing period. For each paddock, all thirty samples were composited in plastic bags at the start (available) and end (residual) of the grazing period. Five sub-samples were taken from each composite, placed in paper bags and dried in a forced air oven at 55°C for 72 h for DM determination. Weights of the dried available and residual forage samples were used to estimate forage utilization by steers according to the Herbage Disappearance Method (Jasmer and Holecheck 1984):

$$Forage\ utilization\ (\%) = \frac{DM\ available\ (g/0.25\ m^2) - DM\ residual\ (g/0.25\ m^2)}{DM\ available\ (g/0.25\ m^2)}$$

Forage intake was estimated using the following equation:

$$DMI(kg\ hd^{-1}\ d^{-1}) = \frac{DM\ available\ (kg) - DM\ residual\ (kg)}{n * \ d}$$

where n = the number of steers per paddock and d = the number of days the paddock was grazed.

Every 14 d throughout the course of the study, five randomly distributed quadrats (0.25 m^2) of forage were clipped from each paddock and immediately dried for DM determination. Pelleted supplements were also sampled every 14 d and immediately dried for DM determination. Forage and pelleted supplement DM were determined by drying samples at 55° C for 72 h in a forced air oven. After dried, forage samples were ground, composited by paddock, and stored until analysis to determine forage quality. At the end of the trial, samples from each pelleted supplement were composited and ground for analysis. All samples were gound to pass a 1-mm screen (Thomas-Wiley Laboratory Mill Model 4; Thomas Scientific, Swedesboro, NJ, USA).

Steer performance was evaluated measuring body weight and subcutaneous body fat thickness. Body weight (BW) was measured over 2 consecutive days at the start and end of trial and every 14 d throughout the course of the trial. Subcutaneous body fat thickness (SCBF) was determined by ultrasound measurement between the 12th and 13th rib at the start and end of the trial using an Aloka SSD-500V ultrasound machine and an Aloka UST-5044 probe (3.5 MHz).

4.2.4. Laboratory analysis

All samples were analyzed in duplicate according to the Association of Official Analytical Chemists (AOAC; 2000) by Cumberland Valley Analytical Services, Inc. (Hagerstown, MD, USA). Samples were analyzed for moisture (analytical DM) by drying at 135° C for 2 h according to the procedure outlined by the Association of Official Analytical Chemists (method #930.15; AOAC 2000). Crude protein (CP) was determined by nitrogen combustion (method 990.03, AOAC 2000) using a Leco FP-528 Nitrogen Combustion Analyzer (Leco, MI, USA). Neutral detergent fibre (NDF) was determined as described in Van Soest *et al.* (1991). Acid detergent fibre (ADF) according to method 973.18 (AOAC 2000). Ash was determined by heating samples at 550° C for four h (method 942.05; AOAC 2000). Calcium and phosphorus were analyzed using the dry ashing procedure (methods 927.02 and 965.17; AOAC 2000, respectively). Calcium was determined using an atomic absorption spectrophotometer (Perkin-Elmer, Model 2380, CN, USA) while P concentration was read at 410 nm on a spectrometer (Pharmacia, LKB-Ultraspec® III, Stockholm, Sweden). Additionally, supplement was analyzed for soluble protein, starch, and fat (ether extract). Soluble protein was detrermined using the Borate-Phosphate procedure as detailed in Krishnamoorthy *et al*. (1982). Starch was analyzed using the method described by Hall (2008), including the use of acetate buffer and correction for free glucose, and ash (method 942.05; AOAC 2000). Ether extract was determined according to method 920.39 (AOAC 2000). Total digestible nutrients (TDN; % DM) and digestible energy (DE; Mcal kg^{-1} DM) were calculated for forage samples using the grass-legume Penn State equation (Appendix Equation A.2) based on ADF, and for supplement samples using the Penn State equation (Appendix Equation A.3) for cereal grains (Adams 1995). Durability of the pellet was measured using a Holmen Pellet Tester (Holmen Chemical Ltd., Borregaard Group, Norsolk, UK), where 100 g sample of pellet was conveyed pneumatically at 60 mbar in a closed circuit for 30 s, followed by sieving through a 2 mm sieve. Pellet durability index (PDI) was recorded as the proportion of the feed not passing through the sieve after treatment in the Holmen tester.

4.2.5. Statistical analysis

The Mixed procedure of SAS (Version 9.2; SAS Inst., Inc., Cary, NC) was used for all statistical analysis. Main effects of treatment on forage utilization, DM, BW (initial, final, and total gain), cumulative ADG, and SCBF (initial and final) were analyzed as a completely randomized design using the Satterthwaite option to estimate denominator degrees of freedom. The statistical model was:

$$y_i = \mu + \tau_i + \varepsilon_i$$

where y_i is the dependent variable, μ is the overall mean, τ_i is the fixed effect of the ith treatment, and ε_i is the error term specific to the experimental unit (paddock) assigned to the ith treatment. Means were separated using Tukey’s method in SAS (Version 9.2; SAS Inst., Inc., Cary, NC). Differences were considered significant when $P < 0.05$.

The effects of treatment, time, and the treatment × time interaction were evaluated for forage quality (CP, ADF, NDF, Ca, P and DE), BW and ADG using a completely randomized design accounting for repeated measures. The statistical model included treatment, time, and the treatment × time interaction as fixed effects. The Satterthwaite option was used to estimate denominator degrees of freedom. Eight covariance structures were tested: simple, compound symmetry, first order autoregressive 1, first order ante-dependence, unstructured, heterogeneous compound symmetry, Toeplitz and heterogeneous autoregressive. The covariance structure with the lowest Akaike’s and Bayesian information criterion (AIC and BIC) values was selected (Littell *et al.* 1998). Least square means were separated using Tukey-Kramer’s method in SAS (Version 9.2; SAS Inst., Inc., Cary, NC). Differences were considered significant when $P < 0.05$.

4.3. Results & Discussion

4.3.1. Supplement composition

The relative proportions of the by-product feeds used in pelleted supplement formulation and chemical composition of the pelleted supplement are given in Table 4.1.

Table 4.1. Ingredient and chemical composition of supplement.

Ingredient (% DM)	
Canola screenings	10.2
DDGS[z]	3.7
Grain screenings	14.8
Oat hulls	14.0
Pea hulls	9.2
Pea screenings	8.5
Peas	9.2
Wheat middlings	34.0
Nutrient (% DM)	
Dry matter (%)	89.1
Crude protein	15.2
Soluble protein (% CP)	35.8
Neutral detergent fibre	30.3
Acid detergent fibre	19.1
Starch	32.0
Fat	7.2
Ash	5.3
Calcium	0.40
Phosphorus	0.40
Total digestible nutrients	76.4
Digestible energy (Mcal kg^{-1} DM)	3.4

[z]DDGS = wheat dried distiller's grains with solubles.

Compared to the average of pelleted supplements of the 2011 study, the relative proportion of canola screenings was increased in the pelleted supplement in order to increase the fat content from 4.4 to 7.2 %. Also, the total CP content of the supplement was decreased from 18.2 to 15.2 % by reducing the relative proportion of DDGS. The soluble fraction of the CP was slightly decreased by 3.7 % (from 39.5 to 35.8 % of total CP). Starch and NDF content in the pelleted supplements were similar (32.0 and 31.1 % respectively). Oat and pea hulls were included as fibre source and starch content was provided mainly by wheat middlings. A portion of the fibre content in the pelleted supplement came from pea hulls in order to make the fibrous fraction more digestible. Pea hulls' fibre digestibility is greater compared to oat hulls (Titgemeyer *et al.* 1991). The DE content was 3.4 Mcal kg^{-1}. Durability of the pellet, measured as PDI, was 91 %. This lower PDI compared to pellets fed in 2011 study can be attributed to the higher fat content in the 2012 pelleted supplement. According to Salmon (1985), fat content in pellets is negatively correlated with durability measured as PDI.

4.3.2. Pasture quality

The nutrient composition of stockpiled crested wheatgrass pasture over the 70 d period of the study is presented in Table 4.2, and the nutrient composition of the pasture across treatment and time (graze period) is presented in Table 4.3.

The average CP content of stockpiled crested wheatgrass pasture over the 70 d of the grazing period was 7.8 %. Also, DE content of the stockpiled crested wheatgrass pasture was 2.3 Mcal kg^{-1} DM. Average CP and energy content in the stockpiled crested wheatgrass pasture were slightly below the requirements of cattle (NRC 2000), with CP and DE being 12 and 14 % below the requirements for the targeted production level. This is consistent with energy being the most limiting nutrient in cool-season grass species (Reid and Jung 1982).

Table 4.2. Chemical composition of stockpiled crested wheatgrass pasture.

Nutrient (% DM)	**Mean ± SD**[z]
Crude protein	7.8 ± 1.5
Neutral detergent fibre	65.6 ± 4.5
Acid detergent fibre	42.5 ± 3.1
Ash	8.0 ± 1.3
Calcium	0.42 ± 0.05
Phosphorus	0.08 ± 0.02
Total digestible nutrients	53.8 ± 3.0
Digestible energy (Mcal kg^{-1} DM)	2.3 ± 0.1

[z]SD = Standard deviation.

Table 4.3. Nutrient composition of stockpiled crested wheatgrass pasture across treatments and time.

	Treatment (trt)[z]				Graze period (gp)							*P* value		
Item[x]	DLY	LA	HA	SEM[y]	1	2	3	4	5	6	SEM[y]	trt	gp	trt×gp
Nutrient (% DM)														
Crude protein	8.1	7.3	8.2	0.28	10.1e	8.9d	7.9c	7.2b	6.6ab	6.3a	0.22	0.11	< 0.01	0.83
NDF	65.7	65.7	65.4	0.39	58.9a	61.6b	65.1c	66.7c	69.3d	71.9e	0.39	0.81	< 0.01	0.17
ADF	42.3a	43.0b	42.3a	0.13	37.7a	40.0b	42.8c	43.4c	44.8d	46.5e	0.23	< 0.01	< 0.01	0.30
Calcium	0.41	0.43	0.41	0.020	0.46b	0.45b	0.40a	0.38a	0.41ab	0.41ab	0.015	0.81	< 0.01	0.70
Phosphorus	0.08	0.07	0.09	0.004	0.12d	0.10c	0.09bc	0.07ab	0.06a	0.06a	0.004	0.09	< 0.01	0.33
DE (Mcal kg^{-1})	2.4b	2.3a	2.4b	0.01	2.6e	2.5d	2.3c	2.3c	2.2b	2.2a	0.01	0.02	< 0.01	0.34

[z]DLY = supplement offered daily at 0.6 % of BW; LA = supplement offered on alternate days at 0.9 % of BW; HA = supplement offered on alternate days at 1.2 % of BW. [y]SEM = pooled standard error of mean. Least square means with different letters in the same row are different ($P < 0.05$) using Tukey-Kramer's method. [x]NDF = neutral detergent fibre; ADF = acid detergent fibre; DE = digestible energy.

As with the previous chapter, forage quality decreased consistently during the grazing period. Stockpiled crested wheatgrass pasture quality was not different ($P \geq 0.11$) across treatments for CP, NDF, and calcium; but phosphorus content tended ($P = 0.09$) to be different. However, ADF was higher ($P < 0.05$) and DE content 4.2 % lower ($P < 0.05$) for pastures in LA relative to DLY and HA. This difference while significant was relatively small.

Time negatively affected ($P < 0.01$) quality of forage for all variables (Table 4.3). Crude protein decreased 37.6 %, while both NDF and ADF increased by 22.1 and 23.3 %, respectively. As expected, DE of forage decreased by 15.4 % (from 2.6 to 2.2 Mcal kg^{-1}) over the study due to the change in ADF content. This negative effect of time on forage quality has been documented for crested wheatgrass (Glover *et al.* 2004; Memmot *et al.* 2011). Also, negative effects of time on forage digestibility have been reported for stockpiled forages (Beck *et al.* 2006) and for stockpiled crested wheatgrass (Baron *et al.* 2004).

4.3.3. Forage utilization

Results for available and residual forage, as well as forage utilization over the 70 d of the grazing period are presented in Table 4.4. Results for estimated forage DM intake across treatments are shown in Table 4.5. Forage availability averaged 21.5 kg of DM hd^{-1} d^{-1} across treatments at the start of the trial. This is more than double the amount (10.0 kg of DM hd^{-1} d^{-1}) required for a 380 kg steer gaining 1 kg d^{-1} (NRC 2000). Available and residual forage were not different ($P = 0.85$ and 0.98 respectively) among treatments. No difference ($P = 0.90$) in forage utilization was observed among treatments.

Table 4.4. Effects of frequency and level of energy supplementation on forage utilization of steers grazing stockpiled crested wheatgrass pasture.

Item	Treatment[z] DLY	LA	HA	SEM[y]	*P* value
Dry matter (%)					
Initial	46.3	46.1	46.7	2.14	0.98
Final	55.7	66.3	60.2	6.94	0.59
Available forage (kg DM ha^{-1})	4265.4	4093.0	4179.1	211.24	0.85
Residual forage (kg DM ha^{-1})	1465.2	1487.5	1464.6	95.52	0.98
Forage utilization (%)	65.2	63.7	65.0	2.50	0.90

[z]DLY = supplement offered daily at 0.6 % of BW; LA = supplement offered on alternate days at 0.9 % of BW; HA = supplement offered on alternate days at 1.2 % of BW. [y]SEM = standard error of mean.

Table 4.5. Effects of frequency and level of energy supplementation on estimated forage and total dry matter intake of steers grazing stockpiled crested wheatgrass pasture.

	Treatment[z]				
Item	DLY	LA	HA	SEM[y]	*P* value
Dry matter intake (kg hd^{-1} d^{-1})					
Supplement	2.4	1.8	2.3	-	-
Pasture	8.0	7.4	7.8	0.59	0.81
Total	10.4	9.2	10.1	0.59	0.40
Dry matter intake (% of BW)					
Supplement	0.6	0.45	0.6	-	-
Pasture	2.0	1.9	2.0	0.14	0.86
Total	2.6	2.3	2.6	0.14	0.44

[z]DLY = supplement offered daily at 0.6 % of BW; LA = supplement offered on alternate days at 0.9 % of BW; HA = supplement offered on alternate days at 1.2 % of BW. [y]SEM = standard error of mean.

Estimated forage DM intakes were not different among treatments either expressed as kg hd^{-1} d^{-1} or as % of BW (P = 0.81 and 0.86 respectively). These results do not correspond with previous findings in the literature that showed a decrease in forage DM intake when growing beef cattle were offered energy supplements on a less frequent basis (Loy *et al.* 2008; Drewnoski *et al.* 2011). This discrepancy can be attributed to the offered amounts and the soluble fraction of the total CP content (DIP) in supplements. Drewnoski *et al.* (2011) offered a combination of soybean hulls and corn gluten feed at 2.73 kg hd^{-1} daily and 6.54 kg hd^{-1}, 3 × per week, which on average was 0.8 % of BW. This is greater than the levels fed in this study. Loy *et al.* (2008) evaluated 3 energy supplements offered at 2 levels (0.21 and 0.81 % of BW), and found that forage DM intake decreased (P < 0.01) when offered less frequently compared to daily at both levels of supplementation. However, supplements fed by Loy *et al.* (2008) showed negative values for predicted DIP balance at both levels of supplementation. According to Drewnoski *et al.* (2011), level of DIP in the diet needs to be above that which would be required for daily supplementation in order to successfully reduce supplementation frequency. In this study, the pelleted supplement had 35.8 % of the total CP content as soluble protein.

4.3.4. Animal performance

Results for the main effect of treatment, main effect of time, and their interaction are shown in Table 4.6. No effect of treatment ($P \geq 0.14$) was observed on BW, total gain and cumulative ADG. Superior animal performance (1.4 kg d^{-1}; P < 0.05) was observed during the first 14 d of the grazing period. As in the 2011 study, this can be attributed to compensatory gain which is the more rapid and efficient growth of animals following a period of restricted feeding (Sainz *et al.* 1995). After the first 14 d of the study, cumulative ADG remained practically constant (1.1 kg d^{-1}) with no difference (P > 0.05) among treatments until 56 d. It is widely documented that as forages mature and reach dormancy, fibre content increases, and both CP content and digestibility of the forage decrease leading to a diminished animal performance (Wallace *et al.* 1963; Park *et al.* 1994; Jung and Allen 1995; Johnson *et al.* 1998). However, supplementation has been shown to maintain animal performance for grazing growing cattle regardless of decreasing pasture quality. Ojowi *et al.* (1996) reported that growing steers supplemented with thin stillage from ethanol production were able to maintain performance over 42 d of grazing diminishing crested wheatgrass pastures.

A treatment × time interaction ($P < 0.01$) was observed for BW (Figure 4.2). When modeling time (d) as a regression variable for all treatments, BW had both a positive linear ($P < 0.01$) component for all treatments and a negative quadratic ($P < 0.01$) component for DLY and LA. According to this analysis, BW increased linearly at 1.7, 1.3 and 1.2 kg d^{-1} for DLY, LA, and HA respectively. In opposition, BW quadratically decreased at 0.008 and 0.005 kg d^{-1} for DLY and LA respectively. The growth for HA group did not show ($P = 0.13$) a negative quadratic effect.

Table 4.6. Effects of frequency and level of energy supplementation (trt), time (d), and their interaction (trt× time) on performance of steers grazing stockpiled crested wheatgrass pasture.

	Treatment (trt)[z]				Day (d)							*P* value		
Item[x]	DLY	LA	HA	SEM[y]	0	14	28	42	56	70	SEM[y]	trt	d	trt×d
BW (kg)	400.5	393.5	393.0	3.27	358.0f	377.0e	386.1d	405.8c	417.9b	429.1a	2.13	0.26	< 0.01	< 0.01
ADG (kg d^{-1})	1.3	1.0	1.0	0.10	-	1.4a	1.0bc	1.1ab	1.1abc	1.0c	0.06	0.14	< 0.01	0.14

[z]DLY = supplement offered daily at 0.6 % of BW; LA = supplement offered on alternate days at 0.9 % of BW; HA = supplement offered on alternate days at 1.2 % of BW. [y]SEM = pooled standard error of mean. Least square means with different letters in the same row are different (P < 0.05) using Tukey-Kramer's method. [x]BW = body weight; ADG = cumulative average daily gain.

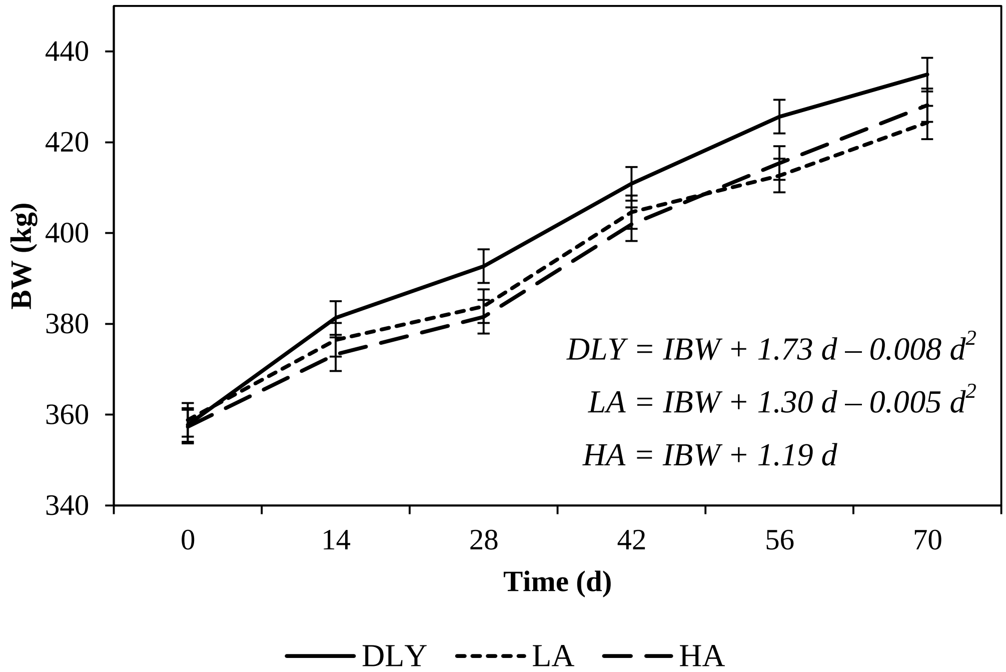

Figure 4.1. Effect of treatment and time interaction on body weight (LSM ± SE) of steers grazing stockpiled crested wheatgrass pastures.

Results for animal performance over the 70 d of grazing period are shown in Table 4.7. Animal performance was very close to the targeted gain of 1 kg d^{-1} and was not affected by supplementation strategy. Final BW, total gain, and cumulative ADG were not different ($P \geq 0.25$) among treatments. This is consistent with findings reported by Drewnoski *et al.* (2011) who observed no change in ADG when growing steers fed fescue hay, were supplemented at 0.8 % of BW with a soy hull and corn gluten feed blend (17 % CP; 45 % NDF; 9 % starch) offered 7 or 3 times per week.

Table 4.7. Effects of frequency and level of energy supplementation on performance of steers grazing stockpiled crested wheatgrass pasture.

	Treatment[z]				
Item[x]	DLY	LA	HA	SEM[y]	*P* value
Body weight (kg)					
Initial	357.8	358.9	357.4	1.15	0.66
Final	434.9	424.4	428.2	4.82	0.36
Total gain	77.2	65.5	70.8	4.40	0.25
ADG (kg d^{-1})					
70 d	1.1	0.9	1.0	0.06	0.25
SCBF (mm)					
Initial	2.5	2.6	2.6	0.12	0.69
Final	3.3	3.6	3.5	0.13	0.23
Change	0.8	1.0	0.9	0.14	0.61

[z]DLY = supplement offered daily at 0.6 % of BW; LA = supplement offered on alternate days at 0.9 % of BW; HA = supplement offered on alternate days at 1.2 % of BW. [y]SEM = standard error of mean. [x]ADG = cumulative average daily gain; SCBF = subcutaneous body fat thickness.

Although the LA group was offered 25 % less supplement, their performance was similar to steers on the HA treatment. This may be attributed to a decrease in ruminal pH and fibre digestibility in the HA group. Ruminal pH of cattle offered an energy supplement on alternate days has been shown to decrease ($P < 0.01$) after supplementation compared to cattle supplemented daily (Drewnoski *et al.* 2012). Moreover, Chase and Hibberd (1989) reported that buffering capacity in ruminal fluid was decreased ($P < 0.01$) by supplementing ground corn on alternate days compared to daily supplementation. In these cited studies and in the HA group of this study, double the daily amount of supplement was offered on days of supplementation for alternate treatments. This increased amount of readily fermentable carbohydrate on alternate days most likely decreased ruminal pH and/or fibre digestion. The inclusion level of readily fermentable carbohydrate in diets for cattle is negatively correlated to ruminal pH, and fibre digestion rate has been shown to decrease with carbohydrate supplementation and decreased pH values (Hoover 1986; Krause and Combs 2003). Therefore, the lack of difference observed between LA and HA groups in terms of animal performance may have resulted from the reduced amount of supplement offered in LA group which could have led to less negative effects on rumen fermentation. Supplementation strategy did not affect ($P \geq 0.23$) final SCBF or the change in this variable over the grazing period.

4.3.5. Economic analysis

Partial economic analysis of this study is presented in Table 4.8. Economic analysis included variable costs relative to feed and yardage costs associated with supplement strategy, equipment use (fuel included), and labour. Fixed costs such as cost of grazing and depreciation were considered constant across treatments and not included in this analysis.

Table 4.8. Economics of frequency and level of supplementation of beef steers grazing stockpiled crested wheatgrass pasture.

	Treatment[z]		
Item	DLY	LA	HA
Feed costs ($ hd^{-1} d^{-1})			
Supplement	0.50	0.37	0.49
Salt/Mineral	0.05	0.05	0.05
Total	0.55	0.42	0.54
Yardage costs ($ hd^{-1} d^{-1})			
Machinery	0.12	0.06	0.06
Labour	0.08	0.04	0.04
Total	0.20	0.10	0.10
Total production cost ($ hd^{-1} d^{-1})	0.75	0.52	0.64
Total cost of gain ($ kg^{-1})	0.68	0.55	0.63
Revenue ($ kg^{-1})	2.20	2.21	2.21
Net profit ($ kg^{-1})	1.52	1.66	1.58
Net profit ($ hd^{-1})	117.48	108.53	112.10

[z]DLY = supplement offered daily at 0.6 % of BW; LA = supplement offered on alternate days at 0.9 % of BW; HA = supplement offered on alternate days at 1.2 % of BW.

Sufficient quantity of supplement was secured for the study in January 2012. Pelleted supplement was obtained from West Central Pelleting (Wilkie, Saskatchewan, Canada) and priced at $178 per tonne (January 2012). Mineral and salt were purchased from FeedRite Ltd. (Humboldt, Saskatchewan, Canada) and priced at $31.50 per 25 kg and $5.25 per block in 2011. Although steers had *ad libitum* access to mineral and salt supplements, amounts offered were recorded for each paddock. Labour was valued at $15.00 per hour. Machinery and equipment rates were valued $36/h (SMA 2012). Cost estimates for labour and truck usage were based on assumption of 30 minutes to feed 150 steers pellets and additional 15 minutes per day to check steers each day. Total costs were calculated in a daily basis per head ($ hd^{-1} d^{-1}) and divided by total gains to generate a cost of gain ($ kg^{-1}).

The revenue as $ kg^{-1} was calculated using the overall five year average (2008-2012) for feeder steers and adjusted according to the difference between the average FBW of each treatment and a 408 kg of BW steer. Profits were divided by total gains to generate a profit of gain ($ kg^{-1} of gain) and according to total gain over 70 d ($ hd^{-1}).

On average, reducing the frequency of supplementation decreased the cost of production by 23 %, and the cost of gain by 13 %. In addition, reducing the amount of supplement offered on alternate days (LA) decreased the production cost by 19 % and the cost of gain by 13 % compared to offering twice the daily amount on alternate days (HA).

Since there was no difference in animal performance among treatments, reducing the supplementation frequency in LA and HA groups increased the profits by 6 % in terms of $ kg^{-1} compared to the DLY group. Moreover, between alternate day supplementation treatments, reducing the amount of supplement offered by 25 % in LA group increased net profits ($ kg^{-1}) by 5 % compared to the HA group.

4.3.6. Beef production

An analysis of the beef production system is presented in Table 4.9. The beef production of the system, in terms of kg and $ produced per land unit on a daily basis, was higher for DLY compared to alternate supplemented treatments. On average, land productivity was 0.4 kg ha^{-1} d^{-1} and \$0.28 ha^{-1} d^{-1} higher for DLY compared to alternate treatments. The HA group had higher productivity between alternate supplemented treatments. However, because no difference was observed among treatments for animal performance, producers should obtain equal kg ha^{-1} but more $ ha^{-1} by offering supplement on alternate days rather than daily.

Table 4.9. Beef production of frequency and level of supplementation of beef steers grazing stockpiled crested wheatgrass.

	Treatment[z]		
Item	DLY	LA	HA
Beef production (kg ha^{-1} d^{-1})	3.1	2.6	2.8
Beef production ($ ha^{-1} d^{-1})	4.66	4.31	4.45

[z]DLY = supplement offered daily at 0.6 % of BW; LA = supplement offered on alternate days at 0.9 % of BW; HA = supplement offered on alternate days at 1.2 % of BW.

4.4. Conclusions

Stockpiled crested wheatgrass forage utilization and intake were not affected by digestible energy supplementation frequency or level of supplement offered on alternate days. Animal performance was not affected by supplementation frequency or level of supplement offered on alternate days. Total costs of the system were reduced by less frequent supplementation; therefore, increasing profits for alternate programs. Moreover, profits can be increased further more by offering a reduced amount of supplement on alternate days.

5. DAILY VERSUS ALTERNATE DAY SUPPLEMENTATION AT TWO LEVELS OF ENERGY FROM BY-PRODUCT FEED PELLETS ON RUMEN FERMENTATION AND DIGESTION OF BEEF HEIFERS FED GRASS HAY.

5.1. Introduction

Stockpiling pastures is a cost effective and practical method of extending the grazing season (Baron *et al.* 2004). However, stockpiling typically takes advantage of growing conditions in late summer and early fall and cool season forages which typically cannot meet livestock nutrient demands during these months (Barnes *et al.* 2003).

Cattle grazing stockpiled pastures are typically deficient in nutrients for maintance and/or growth and under temperate conditions energy has been shown to be the most limiting nutrient in cool-season forages (Reid and Jung 1982). Supplementation of both energy and/or protein has been shown to improve animal performance (DelCurto *et al.* 2000; Kunkle *et al.* 2000); but energy supplementation balanced for protein content has been shown to be more effective under temperate conditions (Galloway *et al.* 1991; Caton and Dhuyvetter 1997; Bohnert *et al.* 2011). However, daily supplementation increases the cost of beef cattle production especially for grazing operations. Supplementing cattle less frequently has the potential to reduce the production costs of grazing cattle operations and to improve productivity (Farmer *et al.* 2001; Cooke *et al.* 2008; Stalker *et al.* 2009; Moriel *et al.* 2012).

Reducing the frequency of protein supplementation has been shown to have no negative effects on animal performance, mainly due to the capacity for nitrogen recycling in ruminants (Krehbiel *et al.* 1998; Huston *et al.* 1999; Bohnert *et al.* 2002). On the other hand, supplementing energy less frequently has been shown to decrease forage intake and animal performance due to a diet substitution effect, and/or disturbed rumen fermentation which negatively affects fibre digestibility. Chase and Hibbert (1989) offered two levels of ground corn daily or at twice the daily amount on alternate days to beef heifers fed low-quality grass hay, and found that reducing the frequency of supplementation consistently decreased fibre digestibility, ruminal pH and buffering capacity of the ruminal liquor. Beaty *et al.* (1994) supplemented daily and on alternate days, four different ratios of sorghum grain and soybean meal to beef steers consuming wheat straw. It was found that straw DM intake, as well as total DM and NDF digestibility decreased as a result of reduced frequency and due to increasing the grain content in the supplement. Moreover, on supplementation days, ruminal pH was lower for the alternate supplemented group compared to the daily group.

Efforts have been made to reduce the negative effects of supplementing energy less frequently by replacing starch with other energy sources such as DDGS and degradable fibre without beneficial results. Loy *et al.* (2007) supplemented 2 levels (0.4 and 0.8 % of BW) of dry-rolled corn and DDGS daily or at twice the daily amount on alternate days to beef heifers fed grass hay. It was concluded that supplementing every other day depressed forage intake but the magnitude of the change was more marked for corn-supplemented heifers than for those fed DDGS. Similarly, Drewnoski and Poore (2012) supplemented daily and twice the amount on alternate days a soybean hull and corn gluten feed blend (14.6 % CP) to beef steers fed medium-quality fescue hay. They reported that hay DM intake decreased ($P < 0.01$) with alternate day supplementation. Moreover, it was observed that ruminal pH was lower ($P < 0.05$) for alternate day supplemented animals on days when supplement was offered while on days when no supplementation was offered, ruminal pH was greater ($P < 0.05$) for alternate compared to daily.

Moore *et al.* (1999) suggested that the probability of negative effects on fibre digestion associated with energy supplementation increases as supplemental amount increases. It is possible that the negative response to reducing the frequency of energy supplementation is due to the fact that on supplementation days, the amount of supplement has been increased in order to achieve equal supplemental energy intake (Mcal d^{-1}) compared to daily supplementation programs. To date, no research has attempted to reduce both the frequency of supplementation as well as the amount of supplement offered.

Therefore, the hypothesis of this research was that the negative effects on forage intake, rumen fermentation, and nutrient digestibility of supplementing digestible energy on alternate days compared to daily supplementation can be mitigated by reducing the amount of supplement offered by 25 % on alternate days relative to those fed twice the daily amount on alternate days.

The objectives of this study were to determine the effects of supplementing a pelleted feed formulated to provide rumen and post-ruminal available energy (starch, degradable fibre, and fat) on forage intake, rumen fermentation, apparent nutrient digestibility and nitrogen balance, when offered daily and on alternate days at two different levels (1.5 and 2 times the daily amount) to beef heifers fed stockpiled crested wheatgrass hay.

5.2. Materials & Methods

All animals were cared for under a University of Saskatchewan Animal Care Protocol in accordance with the guidelines of the Canadian Council on Animal Care (1993).

5.2.1. Study location, Animals and Housing

The trial was conducted in the Livestock Research Building (LRB) at the University of Saskatchewan and initiated in May 2012.

Four ruminally cannulated Herford heifers (BW±SD; 339±12 kg) were housed in individual pens (13.4 m^2). Each pen was equipped with rubber floor mats for footing and automated water bowls. Pens were scraped and cleaned daily before the morning feeding.

5.2.2. Experimental Design

The trial was designed as a 4 × 4 Latin square with 34 d periods. For every period, each heifer was randomly assigned to one of four treatments. Each period included 14 d for dietary adaption (d 1 to 14), 6 d for voluntary intake measurement (d 15 to 20) and 12 d for sample collection (d 21 to 34). During the collection period, rumen fluid samples were collected for two consecutive days (d 21 to 22), indwelling pH data were collected for four consecutive days (d 23 to 26), and total fecal and urine collection were performed for 6 consecutive days (d 29 to 34).

5.2.3. Treatments and Feeding

Treatments consisted of a basal forage diet, and one of four supplementation strategies that differed in frequency and the level of supplement offered. Treatments included: 1) a negative control (CON) where no supplement was offered; 2) a positive control where supplement was offered daily (DLY) at 0.6 % of BW; 3) a low alternate (LA) where supplement was offered on alternate days at 0.9 % of BW and 4) a high alternate (HA) where supplement was offered on alternate days at 1.2 % of BW. The basal forage diet consisted of stockpiled crested wheatgrass hay (Table 5.1) harvested from 8.4 ha located at Lanigan, Saskatchewan. Pastures were composed mainly of long established crested wheatgrass (*Agropyron cristatum* L.), with some smooth bromegrass (*Bromus inermis* L.) and Kentucky bluegrass (*Poa pratensis* L.) invasion in lower moist areas. The pasture had been fertilized with 50 kg ha^{-1} of urea at the start of the growing season and was not grazed until harvested and baled in mid-September 2011. The stockpiled crested wheatgrass hay was coarsely chopped to 10 cm and offered *ad libitum* twice daily at 0800 and 1600 hours. A pelleted supplement was formulated using various by-product feeds as ingredients and a least cost ration software (General System Inc. Version 1.41). The pelleted supplement was designed to meet or exceed the nutritional requirements for 1 kg d^{-1} of gain (NRC 2000) when offered daily at 0.6 % of BW to growing beef cattle (Table 5.1). The pelleted supplement was offered at 0800 h. Grass hay and supplement were offered separately using two different feeders for each heifer. A commercial mineral supplement (15.5 % Ca, 7 % P, 30 ppm Se, 20 ppm Co, 200 ppm I, 1500 ppm Cu, 5000 ppm Mn, 5000 ppm Zn, 1000 ppm Fe, 1.0 ppm F (max), 500 000 IU/kg Vitamin A (min), 50 000 IU/kg Vitamin D (min), 2500 IU/kg Vitamin E (min); Cargill Animal Nutrition, Manitoba, Canada) was offered daily as labeled to all heifers.

5.2.4. Data collection

Dietary adaptation, voluntary intake, and sample collection periods were carried out for an even number of days in order to ensure there were equal numbers of supplementation and non-supplementation days for heifers in alternate day treatments.

Voluntary intake

Following 14 d of adaptation period, voluntary intake was recorded starting on d 15 at 0800 over 6 consecutive days by weighing all feed offered and orts. Offered stockpiled crested wheatgrass hay was sampled twice daily at each feeding. Feed bunks were cleaned each morning and individual orts collected. Daily samples of hay and orts by heifer were dried for 72 hours at 55 °C for dry matter determination. In order to calculate DM intake as a percentage of body weight, heifers were weighed on d 17 and 18 before the morning feeding.

Table 5.1. Ingredient composition of pelleted supplement and nutrient composition of crested wheatgrass hay and pelleted supplement fed to beef heifers.

Item	Grass hay[z]	Supplement
Ingredient (% DM)		
Canola screenings	-	10.2
DDGS	-	3.7
Oat hull	-	14.0
Grain screenings	-	14.8
Wheat middlings	-	34.0
Pea hull	-	9.2
Pea screenings	-	8.5
Peas	-	9.2
Nutrient (%DM)		
Dry matter (%)	84.5 ± 0.04	90.8 ± 0.10
Crude protein	10.2 ± 0.47	15.4 ± 0.07
Soluble crude protein (% CP)	28.6 ± 3.73	29.4 ± 0.07
Neutral detergent fibre	66.1 ± 1.08	30.3 ± 0.64
Acid detergent fibre	42.2 ± 0.32	20.3 ± 1.13
Starch	-	32.0 ± 1.10
Fat	-	7.2 ± 0.28
Ash	8.2 ± 0.36	6.3 ± 0.18
Calcium	0.44 ± 0.09	0.47 ± 0.09
Phosphorus	0.23 ± 0.02	0.44 ± 0.09
Total digestible nutrients	53.2 ± 0.48	73.6 ± 0.81
Digestible energy (Mcal kg^{-1})	2.4 ± 0.01	3.2 ± 0.04

[z] Stockpiled crested wheatgrass hay

Rumen fluid

On d 21 and 22, rumen fluid was collected every 2 h for 12 h starting at 0800 h each day. Samples were obtained by mixing equal volumes (250 ml) collected from three rumen locations (cranial-ventral, ventral and caudal-ventral) as well as a sample from the rumen mat. Subsequently, samples were strained through four layers of cheesecloth. Three 10 mL aliquots of filtrate were sub-sampled into 15 mL tubes. One aliquot was conserved for volatile fatty acid (VFA) analysis by adding 2 ml of 25 % (wt/vol) metaphosphoric acid. Another aliquot was taken for evaluation of ammonia nitrogen (NH_3-N) by adding 2 ml 0.10 M sulphuric acid. The final sub-sample did not receive any addition of preservative and was kept as a spare. All were sealed and immediately stored at -20 °C until analysis.

Volatile Fatty Acid determination

Rumen fluid samples for VFA analysis were thawed at 4 °C overnight, vortexed and centrifuged at 12000 × g at 4 °C for 10 minutes. Subsequently, 1.5 ml of supernatant was transferred in duplicate to a 1.5 ml micro centrifuge tube (Eppendorf®). Micro centrifuge tubes were centrifuged at 16000 × g, at 4 °C for 10 minutes. Subsequently, 1 mL of the supernatant was transferred to gas chromatography (GC) vials. Immediately, 0.2 mL of internal standard (iso-caproic acid) solution was added to the GC vials, vortexed, and refrigerated at 4 °C. A reference sample was also prepared using pure individual VFA of interest (Sigma Aldrich): acetate, propionate, butyrate, valerate, iso-butyrate, and iso-valerate acids. All samples, including reference samples, were quantified by gas chromatography (Agilent 6890 Series GC System with FID, Santa Clara, CA, USA). A standard curve was obtained and used to identify the above mentioned VFAs. The concentration of each VFA was estimated by integrating the area below its respective curve. Total VFA concentration was determined by adding the concentrations of all measured acids (Ghorbani *et al.* 2002; Beauchemin *et al.* 2003).

Ammonia-N (NH_3-N) determination

Ruminal NH_3-N was determined using the phenol hypochlorite method (Broderick and Kang 1980). Samples were thawed at 4 °C overnight, vortexed, and 1.5 mL transferred to micro-centrifuge tubes (Eppendorf®). Micro-centrifuge tubes were kept on ice before centrifuging at 14000 × g at 4 °C for 10 min. After centrifuging, 25 µL of supernatant was then added to test tubes. Subsequently, 1.5 mL of phenol reagent and 1.0 mL of hypochlorite reagent was added and the sample vortexed. Tubes were capped and placed in a 95 °C water bath for 5 minutes. Subsequently, tubes were placed in cold-water for 3 minutes. Finally, 2.5 mL of double distilled water was added and the sample vortexed. Samples were read on spectrophotometer (Pharmacia, LKB-Ultraspec® III, Stockholm, Sweden) at 630 nm. All samples were analyzed in duplicate and kept in ice-water during the entire procedure, except for the water bath stage.

Ruminal pH measurement

Starting on d 23 at 0800 h, ruminal pH was measured and recorded at regular intervals of 60 s, over 96 h using the Lethbridge Research Centre Ruminal pH Measurement System (LRCpH; Model Dascor, Escondido, CA) as described by Penner *et al.* (2006). Each indwelling probe was calibrated in pH 4 and 7 buffer solutions immediately before and after placing them in the ventral sac of the rumen. Each probe was pre-warmed in water (~39 °C) prior to the initial standardization. After removal from the rumen, the probes were washed and kept in warm water (~39 °C) until standardized again. The data was then downloaded and recorded. The shift in millivolt readings from the electrodes between the start and the end of standardization was assumed to be linear, and was used to convert millivolt readings to pH units. The pH data were averaged per minute and summarized daily as mean pH, minimum pH, maximum pH, and the range in pH values. The daily mean pH of CON was used as a threshold to calculate the duration (min d^{-1}) and pH area (min × pH) that each supplemented treatment remained below this point.

Total tract digestibility

Starting on d 29 at 0800 h, total collection of feces and urine was carried out over six days in order to determine apparent total tract nutrient digestibility coefficients and nitrogen balance. Fecal output was collected at 2 (from 0600 h to 2200 h) and 4 h (from 2200 h to 0600 h) intervals from the pen floor, and placed in covered plastic containers for each 24 h period. Daily total fecal output from each heifer was weighed every day at 0800 h. A sub-sample of 5 % of the daily total fecal output was taken after mixing thoroughly and placed in a pre-weighed aluminum drying container, sealed and stored at -20 °C. Total urine output was collected using indwelling catheters (75-mL-capacity balloon, Bardex Foley Catheter, C. R. Bard Inc., Covington, GA) inserted 24 h before (d 28) the start of the total collection period. Urine was collected via Nalgene tubing into 20 L plastic bottles containing 150 mL of concentrated hydrochloric acid. On the first day of urine collection, urine pH was measured to ensure that pH was less than 2 in order to prevent microbial degradation and the loss of volatile NH_3-N. Adjustment of the amount of acid was made if needed. Total urinary output was weighed daily at 0800 h, mixed thoroughly, and samples taken (~10 % of total daily excretion). Daily samples were pooled per heifer for each collection period. After each period, urine was thawed, mixed thoroughly, and subsampled in 500-mL Nalgene bottles in duplicate and stored at -20 °C until analyzed for total N. Offered and refused amounts of stockpiled grass hay were weighed and recorded every day. Samples of grass hay fed and refusals from each heifer were taken daily. Pelleted supplement was sampled at the beginning of each total collection period and kept for analysis. All grass hay fed, ort and supplement samples were dried at 55 °C for 72 h in a forced air oven for DM determination. At the end of each period, frozen fecal samples were thawed and dried at 55 °C in a forced air oven until a constant weight was achieved. Feed, ort and fecal samples were ground to pass a 1-mm screen (Thomas-Wiley Laboratory Mill Model 4; Thomas Scientific, Swedesboro, NJ, USA). Equal portions of ground stockpiled crested wheatgrass hay samples for each day were composited to obtain one sample per experimental period. Ground refusal and fecal samples were composited per heifer according to daily amounts of feed refused and fecal material on a DM basis. All samples were stored individually in plastic vials until analysis. Apparent nutrient digestibility coefficients were determined as the difference between the amount of nutrients consumed and excreted in feces.

5.2.5. Laboratory analysis

All samples were analyzed in duplicate according to the Association of Official Analytical Chemists (AOAC; 2000) by Cumberland Valley Analytical Services, Inc. (Hagerstown, MD, USA). Feed and fecal samples were analyzed for moisture (analytical DM) by drying at 135 ºC for 2 h (method 930.15; AOAC 2000). Crude protein (CP) was determined by nitrogen combustion (method 990.03, AOAC 2000) using a Leco FP-528 Nitrogen Combustion Analyzer (Leco, MI, USA). Neutral detergent fibre (NDF) was determined as described in Van Soest *et al.* (1991). Acid detergent fibre (ADF) was determined according to method 973.18 (AOAC 2000). Ash was determined by heating samples at 550° C during four h (method 942.05; AOAC 2000). Calcium and phosphorus were analyzed using the dry ashing procedure (methods 927.02 and 965.17; AOAC 2000, respectively). Calcium was determined using an atomic absorption spectrophotometer (Perkin-Elmer, Model 2380, CN, USA) while P concentration was read at 410 nm on a spectrometer (Pharmacia, LKB-Ultraspec® III, Stockholm, Sweden).

Additionally, supplement was analyzed for soluble protein, starch, and fat (ether extract). Soluble protein was detrermined using the Borate-Phosphate procedure as detailed in Krishnamoorthy *et al*. (1982). Starch was analyzed using the method described by Hall (2008), including the use of acetate buffer and correction for free glucose, and ash (method 942.05; AOAC 2000). Ether extract was determined according to method 920.39 (AOAC 2000). Gross energy values of feed, refusal and fecal samples were determined using a bomb calorimeter (Model 1281, Parr Instrument Company, Moline, IL). Urine nitrogen was determined by Kjeldahl method of nitrogen determination using a 2400 Kjeltec analyzer unit (method 948.13; AOAC 2000).

5.2.6. Statistical analysis

Three data sets were analyzed for DM intake, rumen VFA and ammonia-N, and pH variables in order to: 1) determine the overall effect (average of all collection days), 2) the effect of supplementation (average of days when supplement was offered to alternate day supplementation treatments), and 3) the effect of no supplementation (average of days when no supplement was offered to alternate day supplementation treatments).

The Mixed procedure of SAS (Version 9.2; SAS Inst., Inc., Cary, NC) was used to complete statistical analysis. Pre-planned contrasts of interest were: 1) CON vs. DLY; 2) DLY vs. LA; and 3) DLY vs. HA. Significant difference was declared at $P < 0.05$, and trends were discussed at $P < 0.10$. Dry matter intake, indwelling pH measurements, apparent nutrient digestibility coefficients, and nitrogen balance were analyzed as a Latin Square design using the Kenward-Roger option to estimate denominator degrees of freedom. The statistical model was:

$$y_{ijk} = \mu + \tau_i + \alpha_j + \beta_k + \varepsilon_{ijk}$$

where y_{ijk} is the dependent variable, μ is the overall mean, τ_i is the fixed effect of treatment, α_j is the fixed effect of period, β_k is the random effect of heifer and ε_{ijk} is the residual error term. Pre-planned contrasts of interest were: 1) CON vs. DLY; 2) DLY vs. LA; and 3) DLY vs. HA. Significance was declared at $P < 0.05$, and trends were discussed at $P < 0.10$.

Rumen VFA and ammonia-N data were analyzed as a Latin square design with repeated measures. The statistical model included period, treatment, time, and treatment × time interaction as fixed effects, and heifer as a random effect. The Kenward-Roger option was used to estimate denominator degrees of freedom. Eight covariance structures were tested: simple, compound symmetry, first order autoregressive 1, first order ante-dependence, unstructured, heterogeneous compound symmetry, Toeplitz and heterogeneous autoregressive. The covariance structure with the lowest (AIC and BIC) Akaike's information criterion values was selected (Littell *et al.* 1998). In case of significant treatment × time interaction effect, least square means were separated using Tukey-Kramer's method in SAS (Version 9.2; SAS Inst., Inc., Cary, NC).

5.3. Results & Discussion

5.3.1. Dry matter intake

Results for hay and total DM intake, as kg d^{-1} and % of BW, are shown in Table 5.2. Overall, hay DM intake (kg d^{-1}) was 12 % lower ($P = 0.04$) for DLY fed heifers compared to those fed CON. This is contrary to results obtained in 2011 grazing study (Table 3.5) where no difference was observed in forage DM intake between supplemented and non-supplemented steers. Hay DM intake of heifers supplemented on alternate days (LA and HA) was not different ($P \geq 0.11$) from that of heifers supplemented every day (DLY). This is consistent with results obtained in 2012 grazing study (Table 4.5) which showed no difference in forage DM intake for steers grazing stockpiled crested wheatgrass pastures and supplemented with the same pelleted supplement offered as in DLY, LA, and HA. Although the amount of supplement offered to LA was 25 % lower compared to DLY, no difference ($P = 0.10$) was observed for total DM intake (kg d^{-1}) between heifers fed DLY and those fed LA. Supplement constituted 23, 19, and 25 % of the total DM intake for heifers fed DLY, LA, and HA respectively.

On days when supplement was offered to alternate treatments, supplement constituted 22, 33, and 41 % of the total DM intake for heifers fed DLY, LA, and HA, respectively. Hay DM intake (kg d^{-1}) of HA heifers was 22 % less ($P < 0.05$) than that of DLY, while no difference ($P = 0.16$) was observed between DLY and LA heifers. In contrast, on days when no supplement was fed to alternate treatments, hay DM intake increased 14 and 15 % for LA and HA respectively compared to supplementation days, and was not different for DLY vs. HA ($P = 0.81$) or DLY vs. LA ($P = 0.48$).

The negative effect of daily energy supplementation vs. no supplementation on forage DM intake has been well documented by Caton and Dhuyvetter (1997) and Kunkle *et al.* (2000). Also, the discrepancy on hay DM intake between supplementation and non-supplementation days observed for DLY vs. HA is consistent with previous findings. Drewnoski and Poore (2012) reported that hay DM intake was lower during supplementation days for beef steers supplemented on alternate days compared to those supplemented daily. In contrast, these workers reported that steers supplemented on alternate days had greater hay DM intake during non-supplementation days.

Table 5.2. Effect of frequency and level of energy supplementation on dry matter intake of beef heifers fed stockpiled grass hay.

	Treatment[z]					*P* values (contrast)		
Item[x]	CON	DLY	LA	HA	SEM[y]	CON vs. DLY	DLY vs. LA	DLY vs. HA
Overall (n = 6)								
DMI (kg d^{-1})								
Hay	8.1	7.1	6.9	6.4	0.28	0.04	0.49	0.11
Supplement	-	2.1	1.6	2.1	-	-	-	-
Total	8.1	9.3	8.4	8.5	0.32	0.03	0.10	0.14
DMI (% of BW)								
Hay	2.2	2.0	1.9	1.8	0.06	0.13	0.17	0.097
Supplement	-	0.6	0.45	0.6	-	-	-	-
Total	2.2	2.6	2.3	2.3	0.06	0.04	0.01	0.09
Supplementation days for LA and HA (n = 3)								
DMI (kg d^{-1})								
Hay	8.3	7.3	6.4	6.0	0.41	0.11	0.16	< 0.05
Supplement	-	2.1	3.2	4.2	-	-	-	-
Total	8.3	9.4	9.6	10.2	0.50	0.15	0.81	0.31
DMI (% of BW)								
Hay	2.3	2.0	1.7	1.6	0.09	0.09	0.05	0.01
Supplement	-	0.6	0.9	1.2	-	-	-	-
Total	2.3	2.6	2.6	2.8	0.08	0.02	0.92	0.11
Non-supplementation days for LA and HA (n = 3)								
DMI (kg d^{-1})								
Hay	7.9	7.0	7.3	6.9	0.29	0.05	0.48	0.81
Supplement	-	2.1	-	-	-	-	-	-
Total	7.9	9.1	7.3	6.9	0.30	0.02	< 0.01	< 0.01
DMI (% of BW)								
Hay	2.1	1.9	2.0	1.9	0.08	0.17	0.66	0.97
Supplement	-	0.6	-	-	-	-	-	-
Total	2.1	2.5	2.0	1.9	0.08	0.02	< 0.01	< 0.01

[z]CON = no supplement offered; DLY = supplement offered daily at 0.6 % of BW; LA = supplement offered on alternate days at 0.9 % of BW; HA = supplement offered on alternate days at 1.2 % of BW. [y]SEM = standard error of mean. [x]DMI = dry matter intake.

This reduced forage DM intake of supplemented heifers could be explained by a diet substitution effect and/or disturbance in rumen fermentation. Although heifers fed DLY consumed 12 % less hay compared to those fed CON, total DM intake was 15 % greater (P = 0.03) for those fed DLY. Moreover, during supplementation days for alternate treatments, heifers fed HA had a hay DM intake 18 % lower ($P < 0.05$) than those fed DLY but no difference (P = 0.31) was observed for total DM intake. In contrast, no difference was observed for hay (P = 0.16) and total (P = 0.81) DM intake between DLY and LA during supplementation days for alternate treatments. As indicated previously, supplement constituted a larger portion of the total DM intake for HA compared to LA.

According to Forbes (2007), voluntary intake in ruminants is controlled by metabolic feedback and/or physical limitations of the rumen. A metabolic feedback in heifers receiving supplemental energy was most likely the reason for the decrease in hay DM intake observed on this group. Moore *et al.* (1999) reviewed the effects of supplementation on voluntary forage intake and concluded that forage intake is reduced by supplementation when the TDN:CP ratio of forage is less than 7, and supplemental TDN intake is more than 0.7 % of BW. On average, the stockpiled crested wheatgrass hay fed in this study had a TDN:CP ratio of 5.2, which confirms energy as the main limiting nutrient, as is commonly seen for cool-season forages (Reid and Jung 1982). This low TDN:CP ratio in stockpiled crested wheatgrass hay most likely affected forage DM intake of heifers supplemented every day (DLY) compared to the non-supplemented animals (CON); contrasting with the results of 2011 grazing trial where the TDN:CP ratio of the forage was higher (6.5) and no difference was observed in forage DM intake between supplemented and non-supplemented animals. Also, supplemental TDN intake for heifers fed HA was 0.87 % of BW which most likely affected hay DM intake during supplementation days; while over the 6 days of collection, average supplemental TDN intake for HA was 0.4 % of BW, which explains the lack of difference on overall hay DM intake for DLY vs. HA. The failure to find a difference in hay DM intake between DLY and LA can also be explained by supplemental TDN intake given that on supplementation days, LA received 0.65 % of BW as supplemental TDN which is slightly below the 0.7 % suggested by Moore *et al.* (1999). A high supplemental TDN intake means increased rumen VFA concentration bringing a negative metabolic feedback on intake (Forbes 2007). During supplementation days for alternate treatments (Table 5.3.3), total VFA concentration of HA was greater ($P < 0.01$) compared to DLY, while for those fed LA tended ($P = 0.08$) to be greater compared to DLY.

In addition, low rumen pH of alternate treatments on supplementation days could have affected fibre digestibility by inhibiting cellulolytic micro-organisms from adhesion to the fibre and/or the growth of rumen bacteria (Russell and Wilson 1996; Mourino *et al.* 1997). Mould and Ørskov (1983) found that decreasing rumen pH to 6.2 by infusing acid into the rumen of sheep fed forage led to a partial inhibition of cellulolysis. Grant and Mertens (1992) observed similar results using an *in vitro* technique. Moreover, when pH was constantly maintained at 6.0, the rumen microflora associated with fibre degradation was completely eliminated decreasing forage DM intake (Mould and Ørskov 1983). In this study, minimum daily pH (Table 5.4) went below 6.0 only for HA (5.90), and was slightly over 6.0 for LA (6.05). However, the average across periods for duration (min d^{-1}) and area (min×pH) below pH 6.2 were 64 and 6.1 respectively, for LA. The average time and area that rumen pH of HA was below 6.2 on supplementation days were125 min d^{-1} and 17.7 min×pH, while below pH 6.0 were 38 min d^{-1} and 5.1 min×pH. For DLY, rumen pH never went below 6.2. However, a decrease in the rate of fibre digestion regardless of rumen pH was observed by Arroquy *et al.* (2005) when NFC sources were added to *in vitro* fermentation cultures of low-quality forage. This negative effect of NFC on fibre digestion rate even when rumen pH is over 6.2 has also been reported by Mould *et al.* (1983) and Piwonka and Firkins (1993).

5.3.2. Rumen fermentation

Rumen fluid volatile fatty acids (VFA)

Overall (Table 5.3.1), a treatment × time interaction ($P < 0.01$) was observed for all measured rumen fermentation parameters except isobutyrate ($P = 0.26$) and isovalerate ($P = 0.13$). Values of VFA concentration in the ruminal fluid sampled at 2 h intervals over 12 h after feeding are shown in Table 5.3.2. Acetate, propionate, butyrate, valerate, and total VFA concentration remained constant ($P > 0.05$) for CON over the 12 h period after feeding. Total VFA concentration of DLY increased 33 % and was greater ($P < 0.05$) vs. CON (84.9 vs. 68.5 m*M*) 2 h after supplementation (1000 h), peaked (88 m*M*) at 1200 h, and remained greater ($P < 0.05$) than those of CON until 6 h after supplementation (1400 h). Acetate, propionate, butyrate, and valerate concentrations were greater ($P < 0.05$) at 2 h after the morning feeding (1000 h) for DLY vs. CON, remaining greater until 1200 h for propionate and valerate, and until 1400 h for butyrate. No difference ($P > 0.05$) was found at any sampling time for DLY vs. LA or HA.

Table 5.3.1. Overall effect of frequency and level of energy supplementation on rumen fluid VFA concentration of beef heifers fed stockpiled grass hay.

	Treatment[z]					*P* value (contrast)			*P* value	
Item[x]	CON	DLY	LA	HA	SEM[y]	CON vs. DLY	DLY vs. LA	DLY vs. HA	Time	Trt×Time
VFA (m*M*)										
Acetate	49.5	53.6	52.5	51.8	2.02	0.04	0.53	0.30	< 0.01	< 0.01
Propionate	12.0	13.2	13.4	13.5	0.49	0.07	0.80	0.73	< 0.01	< 0.01
Butyrate	6.3	8.4	8.2	8.2	0.26	< 0.01	0.54	0.66	< 0.01	< 0.01
Valerate	0.53	0.75	0.68	0.71	0.03	< 0.01	0.16	0.42	< 0.01	< 0.01
Isobutyrate	0.39	0.44	0.45	0.41	0.04	0.34	0.77	0.60	< 0.01	0.26
Isovalerate	0.45	0.56	0.54	0.51	0.05	0.20	0.75	0.51	< 0.01	0.13
Total VFA	69.2	77.1	75.8	75.1	2.67	< 0.01	0.61	0.45	< 0.01	< 0.01
A:P ratio	4.1	4.1	3.9	3.9	0.10	0.71	0.30	0.13	< 0.01	< 0.01

[z]CON = no supplement offered; DLY = supplement offered daily at 0.6 % of BW; LA = supplement offered on alternate days at 0.9 % of BW; HA = supplement offered on alternate days at 1.2 % of BW. [y]SEM = standard error of mean. [x]A:P = acetate:propionate ratio.

Table 5.3.2. Overall effect of treatment × time interaction on rumen fluid VFA concentration of beef heifers fed stockpiled crested wheatgrass hay.

	Time (h)						
Item[z]	0800	1000	1200	1400	1600	1800	2000
Acetate (m*M*)							
CON	50.9	48.6a	49.4	49.4	49.1	49.1	49.9
DLY	46.0	57.1b	60.4	60.0	51.8	51.0	49.3
LA	49.1	51.2ab	52.0	54.2	54.0	53.9	53.1
HA	47.1	49.6ab	50.8	54.7	56.1	53.3	50.7
SEM	2.53	2.53	2.53	2.53	2.53	2.53	2.53
Propionate (m*M*)							
CON	12.0	12.0a	12.1a	11.9	11.8	11.9	12.2
DLY	10.6	15.4b	15.6b	14.3	12.4	12.4	12.0
LA	11.6	13.5ab	13.9ab	14.1	13.4	13.7	13.6
HA	11.6	13.3ab	14.0ab	14.6	14.2	13.5	13.1
SEM	0.66	0.66	0.66	0.66	0.66	0.66	0.66
Butyrate (m*M*)							
CON	6.1	6.4a	6.6a	6.4a	6.3a	6.2a	6.4
DLY	5.9	10.2b	9.8b	9.5b	8.2ab	7.9ab	7.4
LA	6.6	8.7b	8.5ab	8.6b	8.5b	8.4b	7.8
HA	6.0	8.4ab	8.6ab	8.7b	9.2b	8.6b	8.3
SEM	0.37	0.37	0.37	0.37	0.37	0.37	0.37
Valerate (m*M*)							
CON	0.50	0.56a	0.57a	0.53	0.51	0.51	0.54
DLY	0.47	1.02b	1.08b	0.85	0.67	0.61	0.58
LA	0.49	0.71ab	0.84b	0.77	0.66	0.66	0.64
HA	0.49	0.71ab	0.86b	0.85	0.76	0.70	0.64
SEM	0.038	0.046	0.037	0.049	0.045	0.037	0.037
Total VFA (m*M*)							
CON	70.4	68.5a	69.4a	69.0a	68.5	68.5	69.8
DLY	64.0	84.9b	88.0b	85.7b	74.0	72.7	70.1
LA	68.9	75.2ab	76.3ab	78.7ab	77.5	77.6	76.1
HA	66.1	73.0ab	75.2ab	79.8ab	81.2	77.0	73.5
SEM	3.43	3.43	3.43	3.43	3.43	3.43	3.43

[z]CON = no supplement offered; DLY = supplement offered daily at 0.6 % of BW; LA = supplement offered on alternate days at 0.9 % of BW; HA = supplement offered on alternate days at 1.2 % of BW. Total VFA includes isobutyrate and isovalerate. SEM = standard error of mean. Least square means with different letters in the same column are different ($P < 0.05$) using Tukey-Kramer's method.

Examining the main effect of treatment over the 12 h period after the morning feeding (Table 5.3.1), the total VFA concentration of DLY was 11.4 % greater ($P < 0.01$) compared to CON, but did not differ for DLY vs. LA ($P = 0.61$) and HA ($P = 0.45$). This is consistent with Loy *et al.* (2007) who reported greater ($P < 0.05$) total VFA concentration for heifers supplemented with either dry-rolled corn or DDGS compared to non-supplemented animals, but no difference for daily supplementation vs. twice the daily amount offered every other day. Acetate, butyrate, and valerate concentrations were greater ($P \leq 0.04$) and propionate tended to be greater ($P = 0.07$) for DLY compared to CON. Individual VFA's concentrations did not differ for DLY vs. LA ($P \geq 0.16$) and DLY vs. HA ($P \geq 0.30$). No difference was observed ($P \geq 0.13$) for the acetate:propionate ratio.

On days when supplement was offered to alternate treatments (Tables 5.3.3), a treatment × time interaction ($P \leq 0.03$) was observed for all measured rumen fermentation parameters except isobutyrate ($P = 0.91$) and isovalerate ($P = 0.40$). Values of VFA concentration in the ruminal fluid sampled at 2 h intervals over 12 h after feeding are shown in Table 5.3.4. Total VFA concentration of DLY increased 23 %, 2 h after supplementation (1000 h), and peaked (88.6 m*M*) at 4 h after supplementation (1200 h). Total VFA concentration of HA increased 64 % over the 8 h period after supplementation and peaked (105.4 m*M*) at 1600 h at which point it was greater ($P < 0.05$) than DLY (73.2 m*M*). A similar pattern was observed for total VFA concentration curves of beef steers supplemented daily, and at twice the daily amount on alternate days by Drewnoski and Poore (2012). Total VFA concentration of LA increased rapidly (31 %) 2 h after supplementation, and then increased at a lower rate (10 %) during the next 4 h until peaking (92.5 m*M*) at 1400 h. However, no difference ($P > 0.05$) was observed at any time point for total VFA concentration between DLY and LA.

Table 5.3.3. Effect on supplementation day for alternate treatments of frequency and level of energy supplementation on rumen fluid VFA concentration of beef heifers fed stockpiled grass hay.

	Treatment[z]					*P* value (contrast)			*P* value	
Item[x]	CON	DLY	LA	HA	SEM[y]	CON vs. DLY	DLY vs. LA	DLY vs. HA	Time	Trt*Time
VFA (m*M*)										
Acetate	50.7	54.1	57.6	60.2	2.33	0.17	0.17	0.03	0.01	0.02
Propionate	12.3	13.4	15.1	15.9	0.45	0.096	0.02	< 0.01	< 0.01	< 0.01
Butyrate	6.5	8.6	9.4	10.1	0.33	< 0.01	< 0.10	< 0.01	< 0.01	0.01
Valerate	0.54	0.76	0.83	0.91	0.03	< 0.01	0.21	0.02	< 0.01	< 0.01
Isobutyrate	0.40	0.45	0.47	0.44	0.04	0.39	0.84	0.87	0.04	0.91
Isovalerate	0.47	0.58	0.58	0.61	0.06	0.08	0.91	0.58	< 0.01	0.40
Total VFA	70.9	77.9	84.0	88.2	2.97	0.047	0.08	< 0.01	< 0.01	< 0.01
A:P ratio	4.1	4.1	3.9	3.8	0.13	0.72	0.18	0.11	< 0.01	0.03

[z]CON = no supplement offered; DLY = supplement offered daily at 0.6 % of BW; LA = supplement offered on alternate days at 0.9 % of BW; HA = supplement offered on alternate days at 1.2 % of BW. [y]SEM = standard error of mean. [x]A:P = acetate:propionate ratio.

Table 5.3.4. Treatment × time interaction on supplementation day for alternate treatments on rumen VFA concentration of beef heifers fed stockpiled crested wheatgrass hay.

	Time (h)						
Item	0800	1000	1200	1400	1600	1800	2000
Acetate (m*M*)							
CON	54.0	52.0	50.2	50.7	49.6	48.7	49.8
DLY	49.4	56.9	60.4	59.6	51.2	51.3	50.1
LA	46.2	56.1	56.9	62.9	63.9	60.0	57.3
HA	46.2	54.1	59.8	67.6	72.4	64.0	57.2
SEM	2.94	3.26	2.82	4.40	4.55	3.35	2.62
Propionate (m*M*)							
CON	12.7	12.7	12.3	12.3	12.2	11.8	11.9
DLY	11.5	15.5	15.8	14.2	12.2	12.4	12.1
LA	10.7	15.6	16.1	17.1	15.9	15.2	15.1
HA	11.2	15.1	17.3	18.6	18.3	16.1	14.9
SEM	0.84	0.84	0.84	0.84	0.84	0.84	0.84
Butyrate (m*M*)							
CON	6.4	6.8a	6.8	6.7	6.4	6.2	6.5a
DLY	6.4	10.3b	10.0	9.4	8.2	8.1	7.7ab
LA	5.9	10.4b	9.9	10.5	10.6	9.9	8.9ab
HA	5.5	9.8b	10.6	11.3	12.5	10.9	10.3b
SEM	0.42	0.64	0.45	0.67	0.69	0.49	0.36
Valerate (m*M*)							
CON	0.51	0.59	0.59a	0.55a	0.52a	0.50a	0.54
DLY	0.51	0.99	1.12b	0.84ab	0.66a	0.62ab	0.60
LA	0.46	0.89	1.12b	1.02ab	0.82ab	0.75ab	0.74
HA	0.45	0.85	1.18b	1.20b	1.05b	0.88b	0.76
SEM	0.040	0.061	0.072	0.075	0.052	0.043	0.054
Total VFA (m*M*)							
CON	74.6	73.1	70.8a	71.0	69.3a	68.0a	69.7
DLY	69.0	85.0	88.6ab	85.0	73.2a	73.2ab	71.4
LA	64.3	84.2	85.1ab	92.5	92.1ab	86.7ab	83.0
HA	64.4	80.9	90.0b	99.7	105.4b	92.9b	84.1
SEM	4.05	4.78	3.79	5.98	5.69	4.10	3.91

[z]CON = no supplement offered; DLY = supplement offered daily at 0.6 % of BW; LA = supplement offered on alternate days at 0.9 % of BW; HA = supplement offered on alternate days at 1.2 % of BW. Total VFA includes isobutyrate and isovalerate. SEM = standard error of mean. Least square means with different letters in the same column are different ($P < 0.05$) using Tukey-Kramer's method.

Acetate, propionate, butyrate, and valerate concentrations increased for all supplemented treatments right after supplementation (0800 h). For DLY, butyrate concentration peaked at 1000 h while acetate, propionate, and valerate concentrations peaked at 1200 h. In contrast, individual VFA concentrations of LA and HA continued increasing longer compared to those of DLY. For both alternate groups, acetate and butyrate peaked at 1600 h while propionate peaked at 1400 h. Valerate concentration of HA peaked at 1400 h and was greater ($P < 0.05$) at 1600 h compared to DLY. No difference ($P > 0.05$) was observed for individual VFA concentration between DLY and LA.

Examining the main effect of treatment over the 12 h period after the morning feeding (Table 5.3.3), the total VFA concentration of LA tended to be 8 % greater ($P = 0.08$) compared to DLY, and HA was 13 % greater ($P < 0.01$) vs. DLY. Acetate, propionate, butyrate, and valerate concentrations were greater ($P \leq 0.03$) for HA compared to DLY. For DLY vs. LA, butyrate tended ($P < 0.10$) and propionate was greater ($P = 0.02$) for LA, and no difference ($P \geq 0.17$) was observed for other individual VFA concentrations. No difference was observed ($P \geq 0.11$) for acetate:propionate ratio for DLY vs. LA and DLY vs. HA.

Table 5.3.5. Effect on no supplementation day of frequency and level of energy supplementation on rumen VFA concentration of beef heifers fed stockpiled grass hay.

	Treatment[z]					*P* value (contrast)			*P* value	
Item[x]	CON	DLY	LA	HA	SEM[y]	CON vs. DLY	DLY vs. LA	DLY vs. HA	Time	trt×time
VFA (m*M*)										
Acetate	48.3	53.2	47.4	43.3	3.78	0.38	0.31	< 0.10	0.09	< 0.01
Propionate	11.7	13.1	11.7	11.0	0.75	0.22	0.22	0.08	< 0.01	< 0.01
Butyrate	6.1	8.2	6.9	6.4	0.48	0.01	0.09	0.03	< 0.01	< 0.01
Valerate	0.52	0.74	0.53	0.52	0.04	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Isobutyrate	0.38	0.42	0.44	0.38	0.03	0.20	0.58	0.16	< 0.01	< 0.01
Isovalerate	0.43	0.53	0.49	0.42	0.04	0.01	0.23	<0.01	< 0.01	0.01
Total VFA	67.4	76.2	67.5	62.0	3.98	0.15	0.15	0.03	0.02	< 0.01
A:P ratio	4.1	4.1	4.1	3.9	0.12	0.73	0.95	0.26	< 0.01	< 0.01

[z]CON = no supplement offered; DLY = supplement offered daily at 0.6 % of BW; LA = supplement offered on alternate days at 0.9 % of BW; HA = supplement offered on alternate days at 1.2 % of BW. [y]SEM = standard error of mean. [x]A:P = acetate:propionate ratio.

Table 5.3.6. Treatment × time interaction on no supplementation day for alternate treatments on rumen VFA concentration of beef heifers fed stockpiled grass hay.

	Time (h)						
Item	0800	1000	1200	1400	1600	1800	2000
Acetate (m*M*)							
CON	47.7	45.2	48.5	48.1	48.6	49.4	50.1
DLY	42.5	57.2	60.3	60.5	52.3	50.7	48.5
LA	52.1	46.2	47.1	45.5	44.2	47.8	48.9
HA	47.9	45.2	41.9	41.8	39.9	42.6	44.1
SEM	5.74	4.91	3.84	4.92	3.39	3.32	1.88
Propionate (m*M*)							
CON	11.3	11.2	11.9ab	11.5	11.7	12.1	12.3
DLY	9.7	15.3	15.3b	14.4	12.7	12.4	11.9
LA	12.4	11.4	11.8ab	11.2	10.9	12.2	12.2
HA	12.0	11.5	10.7a	10.6	10.0	11.0	11.3
SEM	1.12	0.95	0.74	1.12	0.86	0.84	0.66
Butyrate (m*M*)							
CON	5.7	6.1a	6.3a	6.1	6.1	6.2	6.2
DLY	5.5	10.0b	9.6b	9.5	8.2	7.7	7.2
LA	7.3	7.1ab	7.2ab	6.8	6.4	7.0	6.8
HA	6.5	6.9ab	6.5a	6.1	5.9	6.3	6.4
SEM	0.80	0.62	0.50	0.73	0.47	0.39	0.29
Valerate (m*M*)							
CON	0.49	0.52a	0.54a	0.51	0.50	0.52	0.53
DLY	0.43	1.04b	1.04b	0.85	0.68	0.60	0.56
LA	0.53	0.54ab	0.57a	0.51	0.48	0.57	0.53
HA	0.52	0.57ab	0.54a	0.49	0.47	0.52	0.51
SEM	0.048	0.073	0.044	0.074	0.046	0.027	0.034
Total VFA (m*M*)							
CON	66.2	63.9	68.1ab	67.0	67.7	69.0	69.8
DLY	59.1	84.8	87.4b	86.3	74.8	72.3	68.9
LA	73.5	66.2	67.6ab	64.8	62.8	68.5	69.2
HA	67.9	65.2	60.4a	59.8	57.0	61.0	63.0
SEM	6.83	5.91	4.40	6.06	3.68	3.59	1.96

[z]CON = no supplement offered; DLY = supplement offered daily at 0.6 % of BW; LA = supplement offered on alternate days at 0.9 % of BW; HA = supplement offered on alternate days at 1.2 % of BW. Total VFA includes isobutyrate and isovalerate. SEM = standard error of mean. Least square means with different letters in the same column are different ($P < 0.05$) using Tukey-Kramer's method.

On days when no supplement was offered to alternate treatments (Tables 5.3.5), a treatment × time interaction ($P \leq 0.01$) was also observed for all measured rumen fermentation parameters. Values of VFA concentration in the rumen fluid sampled at 2 h intervals over the 12 h period after feeding are shown in Table 5.3.6. Contrary to supplementation days, total VFA concentration of LA and HA decreased (15 and 16 % respectively) constantly during 8 h after morning feeding, reaching their nadir (62.8 and 57.0 m*M* respectively) at 1600 h. This can be attributed to the fact that, besides not receiving supplement, absorption of VFA for LA and HA was greater due to a lower rumen pH during the previous day after supplement was offered. It has been reported that as rumen pH decreases, the absorption of VFA (m*M* h^{-1}) increases (Dijkstra *et al.* 1993). At 1200 h, total VFA concentration was lower ($P < 0.05$) for HA (60.4 m*M*) compared to DLY (87.4 m*M*). No difference was observed for total VFA concentration of DLY vs. LA at any point during the 12 h period after feeding. Acetate, propionate, butyrate, and valerate concentrations of DLY increased right after supplementation (0800 h) and peaked at some point between the 1000 and 1400 h. In contrast, individual VFA concentrations of LA and HA remained constant ($P > 0.05$) during the 12 h after feeding. At 1200 h, propionate and butyrate concentrations were greater ($P < 0.05$) for DLY compared to HA, and valerate concentration was greater for DLY compared to LA and HA.

Examining the main effect of treatment over the 12 h period after the morning feeding (Table 5.3.5), total VFA concentration was lower ($P = 0.03$) for HA compared to DLY, and no difference ($P = 0.15$) was observed for DLY vs. LA. Butyrate, valerate, and isovalerate concentrations of HA were lower ($P \leq 0.03$) vs. DLY, while acetate and propionate concentrations tended to be lower ($P < 0.10$ and $P = 0.08$ respectively). No difference was observed ($P \geq 0.09$) for individual VFA concentration between DLY and LA, except valerate which was greater ($P < 0.01$) for DLY. No difference was observed ($P \geq 0.26$) for acetate:propionate ratio for DLY vs. LA and DLY vs. HA.

The relative change in VFA concentration observed for HA, greater on supplementation days and lower on non-supplementation days, has also been reported by Drewnoski and Poore (2012) and Loy *et al.* (2007) when growing cattle were offered twice the daily amount of supplement on alternate days. In this study, the total VFA concentration of HA on supplementation days was 42 % greater compared to non-supplementation days. A similar relative change in the VFA concentration was also observed for LA. However, the magnitude of the change was lower than with HA. The total VFA concentration of LA was 24 % greater on supplementation days compared to non-supplementation days and not different to DLY.

Rumen fluid ammonia-N (NH_3-N)

Overall (Table 5.3.7), a treatment × time interaction ($P \leq 0.01$) was observed. Values of NH_3-N concentration in the rumen fluid sampled at 2 h intervals over the 12 h period after feeding are shown in Table 5.3.8. Following feeding, the NH_3-N concentrations of CON and DLY increased (51 and 318 % respectively), and peaked (CON = 5.6 mg dL^{-1}; DLY = 12.7 mg dL^{-1}) 2 h after feeding (1000 h) at which point NH_3-N concentration was greater ($P > 0.05$) for DLY. Levels of NH_3-N remained higher for DLY (7.2 mg dL^{-1}) compared to CON (4.0 mg dl^{-1}) until 1200 h. The nadir for CON (1.4 mg dL^{-1}) and DLY (1.9 mg dL^{-1}) were both reached at 1400 h, and no difference ($P > 0.05$) was observed from this point for the reminder of the sampling period.

Table 5.3.7. Effect of frequency and level of energy supplementation on rumen fluid ammonia-N (NH_3-N) concentration of beef heifers fed stockpiled grass hay.

	Treatment[z]					*P* value (contrast)			*P* value	
Item	CON	DLY	LA	HA	SEM[y]	CON vs. DLY	DLY vs. LA	DLY vs. HA	Time	trt×time
Overall										
NH_3-N (mg dL^{-1})	3.4	4.6	5.8	4.3	0.25	< 0.01	< 0.01	0.37	< 0.01	< 0.01
Supplementation day for LA and HA										
NH_3-N (mg dL^{-1})	3.2	4.8	7.0	5.4	0.48	0.03	< 0.01	0.32	< 0.01	< 0.01
Non-supplementation day for LA and HA										
NH_3-N (mg dL^{-1})	3.7	4.4	4.6	3.3	0.41	0.09	0.71	0.02	< 0.01	< 0.01

[z]CON = no supplement offered; DLY = supplement offered daily at 0.6 % of BW; LA = supplement offered on alternate days at 0.9 % of BW; HA = supplement offered on alternate days at 1.2 % of BW. [y]SEM = standard error of mean.

Table 5.3.8. Treatment × time interaction on rumen ammonia-N (NH_3-N) concentration of beef heifers fed stockpiled crested wheatgrass hay.

	Time (h)						
Item	0800	1000	1200	1400	1600	1800	2000
Overall							
NH_3-N (mg dL^{-1})							
CON	3.7	5.6a	4.0a	1.9a	2.3	3.3ab	3.1
DLY	4.0	12.7c	7.2b	1.4a	2.0	2.1a	2.9
LA	5.1	9.6b	8.7b	5.1b	3.7	4.9b	3.4
HA	2.8	8.1ab	7.5b	3.8ab	2.6	2.6ab	3.1
SEM	0.49	0.49	0.49	0.49	0.49	0.49	0.49
Supplementation day for LA and HA							
NH_3-N (mg dL^{-1})							
CON	2.7a	5.4a	4.2a	1.8ab	2.2	2.8	3.2
DLY	4.5bc	12.7b	8.2ab	1.2a	1.9	1.9	2.9
LA	5.6c	13.6b	13.1b	6.2c	3.6	4.1	2.8
HA	3.2ab	11.4b	11.8b	5.1bc	2.2	1.6	2.5
SEM	0.35	1.02	0.88	0.65	0.73	0.85	0.62
Non-supplementation day for LA and HA							
NH_3-N (mg dL^{-1})							
CON	4.8	5.7a	3.8	2.0	2.5	3.9	3.1
DLY	3.4	12.6b	6.1	1.6	2.2	2.4	2.9
LA	4.5	5.7a	4.3	4.1	3.8	5.8	4.1
HA	2.3	4.7a	3.2	2.5	3.0	3.6	3.6
SEM	0.72	0.72	0.72	0.72	0.72	0.72	0.72

[z]CON = no supplement offered; DLY = supplement offered daily at 0.6 % of BW; LA = supplement offered on alternate days at 0.9 % of BW; HA = supplement offered on alternate days at 1.2 % of BW.
[y]SEM = standard error of mean. Least square means with different letters in the same column are different (P < 0.05) using Tukey-Kramer's method.

Examining the main effect of treatment over the 12 h period after the morning feeding (Table 5.3.7), the NH_3-N concentration of DLY was greater ($P < 0.01$) compared to CON, lower ($P < 0.01$) compared to LA, and not different ($P = 0.37$) compared to HA. This is similar to results reported by Loy *et al.* (2007) who found that beef heifers supplemented daily at 0.4 % of BW had greater ($P < 0.05$) NH_3-N to those receiving no supplement, and NH_3-N tended to be greater ($P = 0.07$) for heifers supplemented twice the daily amount (0.8 % of BW) on alternate days vs. those supplemented daily.

On days when supplement was offered to alternate treatments (Table 5.3.7), a treatment × time interaction ($P \leq 0.01$) was observed. Values of NH_3-N concentration in the rumen fluid sampled at 2 h intervals over the 12 h period after feeding are shown in Table 5.3.8. The NH_3-N concentration increased 243 % for LA and 356 % for HA at 2 h after supplementation (1000 h). Peaks were reached at 1000 h for LA (13.6 mg dL^{-1}), and at 12000 h for HA (11.8 mg dL^{-1}). Levels of NH_3-N at peak points of alternate treatments were not different ($P > 0.05$) to those of DLY at same times. This similarity at peak between daily and alternate supplemented treatments is contrary to results reported by Drewnoski and Poore (2012), who observed that peak NH_3-N concentration on supplementation day was greater ($P < 0.01$) for alternate compared to daily supplemented beef steers. After peaking, NH_3-N concentration of LA decreased 74 % until 1600 h, and decreased 86 % until 1800 h for HA. At 1400 h, NH_3-N concentration of LA and HA (6.2 and 5.1 mg dL^{-1} respectively) were greater ($P < 0.05$) compared to DLY (1.2 mg dL^{-1}). Examining the main effect of treatment over the 12 h period after the morning feeding (Table 5.3.7), the NH_3-N concentration of DLY was lower ($P < 0.01$) compared to that of LA, but not different ($P = 0.32$) compared to that of HA.

On days when no supplement was offered to alternate treatments (Table 5.3.7), a treatment × time interaction ($P \leq 0.01$) was observed. Values of NH_3-N concentration in the rumen fluid sampled at 2 h intervals over the 12 h period after feeding are shown in Table 5.3.8. The NH_3-N concentrations of LA and HA remained practically constant during the 12 h period after morning feeding, with no change ($P > 0.05$) at any sampling time. At 2 h after morning feeding (1000 h), NH_3-N concentration of DLY was greater ($P < 0.05$) compared to LA and HA, but no difference ($P > 0.05$) was observed at any other sampling time for DLY vs. LA or HA. Examining the main effect of treatment over the 12 h period after the morning feeding (Table 5.3.7), the NH_3-N concentration of DLY was greater ($P = 0.02$) compared to HA, but not different ($P = 0.71$) when compared to LA.

For all treatments, the NH_3-N concentration averaged over the 12 h period after morning feeding was adequate for microbial growth, but not all treatments had adequate NH_3-N concentration for fibre digestion. According to Boniface *et al.* (1986) and Hoover (1986), the minimum NH_3-N concentration for optimal microbial growth is 3.3 mg dL^{-1}; while for optimal fibre digestion, NH_3-N concentration needs to range from 4.5 to 6.2 mg dL^{-1}. In this study, the lowest values for mean NH_3-N concentration over the 12 h period after morning feeding were observed for CON (3.4 mg dL^{-1}), and for HA (3.3 mg dL^{-1}) during non-supplementation days.

The magnitude of change in NH_3-N concentration of HA was greater compared to LA. On supplementation day, NH_3-N concentration of HA was 64 % greater compared to no supplementation day while for LA it was 52 % greater on supplementation day.

Rumen pH

Results for daily rumen pH, and parameters below a rumen pH threshold value of 6.75 which was the daily mean rumen pH for the CON treatment over the 4 collection days (overall), the supplementation days, and non-supplementation days for alternate treatments, are shown in Table 5.4.

Overall, mean and minimum daily rumen pH decreased ($P = 0.01$) with daily supplementation compared to no supplementation (CON vs. DLY). Also, daily rumen pH range of DLY was greater ($P < 0.01$) vs. CON. A similar effect on rumen pH of growing beef cattle fed grass hay and receiving daily energy supplementation has been reported by Grigsby *et al.* (1993) and Loy *et al.* (2007). Grigsby *et al.* (1993) found that rumen pH of beef steers fed bromegrass hay decreased when supplemented with four different soybean hull:ground corn ratios compared to a non-supplemented group. A similar observation was documented by Loy *et al.* (2007) when beef heifers were supplemented with either dry-rolled corn or DDGS compared to a non-supplemented control group. Figure 5.1 shows the overall mean rumen pH value recorded every minute over a 24 h period for all treatments. It can be observed that the rumen pH remains practically constant for CON with values around the daily mean rumen pH (dashed line) which was used as threshold. On the other hand, rumen pH value of DLY dropped drastically right after supplementation (0800 h) remaining below the threshold value for most of the day. Although no difference ($P = 0.16$) was observed between CON vs. DLY for duration below the threshold, the area below this point was greater ($P = 0.02$) for DLY compared to CON.

Table 5.4. Effect of frequency and level of energy supplementation on daily rumen pH parameters of beef heifers fed stockpiled grass hay.

	Treatment[z]					*P* value (contrast)		
Item	CON	DLY	LA	HA	SEM[y]	CON vs. DLY	DLY vs. LA	DLY vs. HA
Overall (n = 4)								
Daily rumen pH								
Mean	6.75	6.65	6.70	6.72	0.03	0.01	0.18	0.04
Minimum	6.50	6.23	6.26	6.22	0.05	< 0.01	0.48	0.82
Maximum	7.01	7.04	7.07	7.11	0.03	0.34	0.50	0.05
Range	0.50	0.82	0.81	0.90	0.03	< 0.01	0.75	0.12
Rumen pH < 6.75								
Duration (min d^{-1})	707	913	692	540	140.0	0.16	0.14	0.03
Area (pH*min)	62.2	179.0	146.6	154.2	31.78	0.02	0.45	0.51
Supplementation days for LA and HA (n = 2)								
Daily rumen pH								
Mean	6.74	6.64	6.60	6.59	0.02	< 0.01	0.09	0.04
Minimum	6.48	6.22	6.05	5.90	0.07	0.03	0.13	0.01
Maximum	7.00	7.04	7.08	7.09	0.03	0.17	0.28	0.15
Range	0.52	0.82	1.02	1.20	0.07	0.01	0.06	< 0.01
Rumen pH < 6.75								
Duration (min d^{-1})	720	923	923	840	149.1	0.34	0.99	0.70
Area (pH*min)	62.9	185.9	262.8	291.7	32.88	< 0.01	0.03	< 0.01
Non-supplementation days for LA and HA (n = 2)								
Daily rumen pH								
Mean	6.75	6.67	6.79	6.85	0.04	0.07	0.03	< 0.01
Minimum	6.53	6.24	6.46	6.54	0.08	0.02	0.07	0.02
Maximum	7.01	7.05	7.05	7.14	0.04	0.47	0.93	0.14
Range	0.48	0.82	0.59	0.60	0.04	< 0.01	< 0.01	< 0.01
Rumen pH < 6.75								
Duration (min d^{-1})	694	903	461	240	159.6	0.15	0.01	< 0.01
Area (pH*min)	67.4	165.0	31.4	16.8	37.51	0.07	0.03	0.02

[z]CON = no supplement offered; DLY = supplement offered daily at 0.6 % of BW; LA = supplement offered on alternate days at 0.9 % of BW; HA = supplement offered on alternate days at 1.2 % of BW.
[y]SEM = standard error of mean.

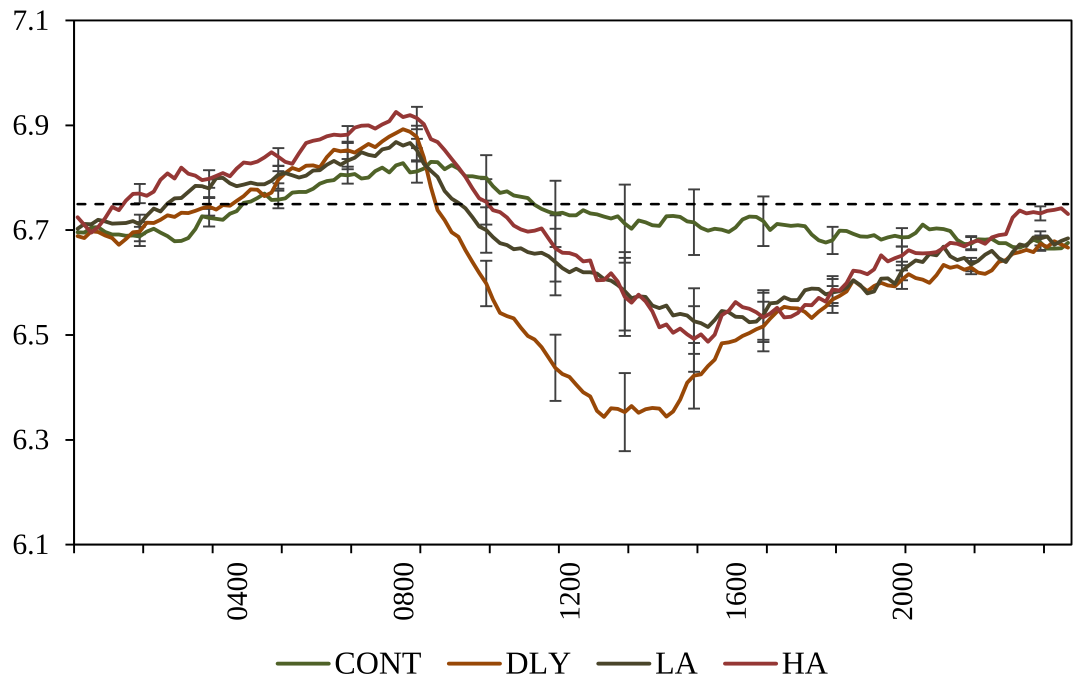

Figure 5.1. Overall effect of frequency and level of energy supplementation on daily rumen pH (mean ± SE) of beef heifers fed stockpiled grass hay.

On the day when supplement was offered to alternate treatments, mean and minimum daily rumen pH of HA were lower ($P \leq 0.04$) compared to DLY, and the range in pH was greater ($P < 0.01$) for HA vs. DLY. Mean and range of daily rumen pH tended to be lower ($P = 0.09$) and greater ($P = 0.06$) respectively, for LA compared to DLY and no difference ($P \geq 0.13$) was observed for minimum and maximum pH. Figure 5.2 shows the supplementation day mean rumen pH value recorded every minute over a 24 h period for all treatments. It can be observed that the rumen pH value of supplemented treatments dropped drastically right after supplementation (0800 h) remaining below the threshold value (dashed line) for most of the day. Although no difference ($P \geq 0.70$) was observed between DLY and alternate treatments for duration below threshold, the area below this point was greater ($P \leq 0.03$) for LA and HA.

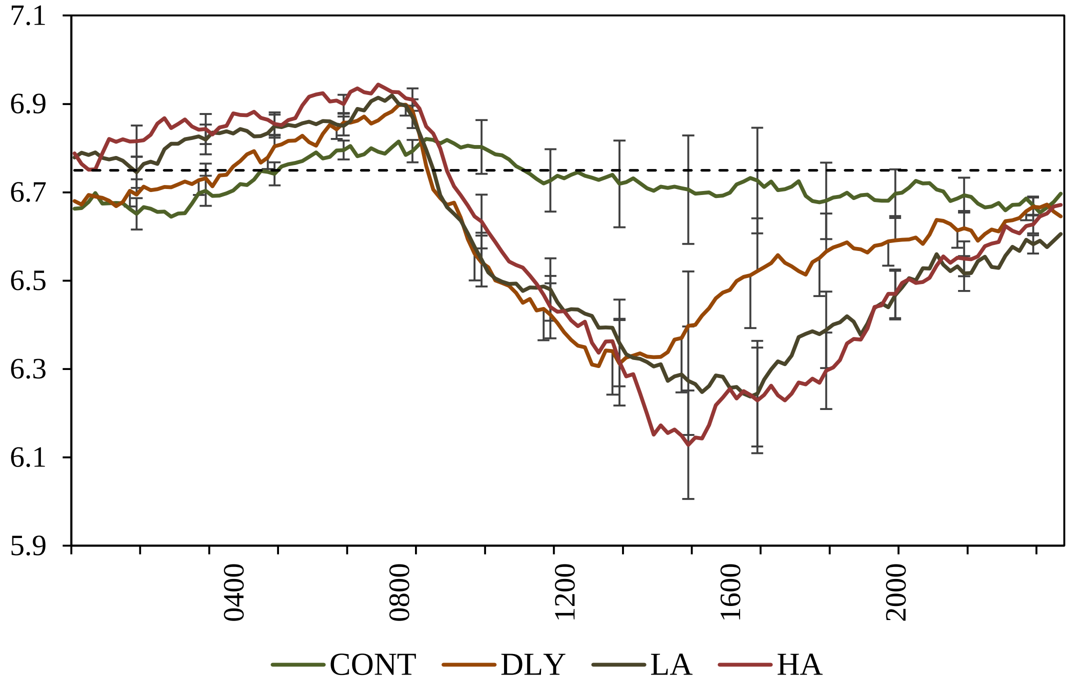

Figure 5.2. Effect on supplementation day for alternate treatments of level of energy supplementation on daily rumen pH (mean ± SE) of beef heifers fed stockpiled grass hay.

On days when no supplement was offered to alternate treatments, mean daily rumen pH increased for alternate treatments and were greater ($P \leq 0.03$) compared to DLY. Also, minimum daily pH of DLY was lower ($P = 0.02$) compared to HA and tended ($P = 0.07$) to be lower vs. LA. The range in pH decreased ($P < 0.01$) for LA and HA relative to DLY. Figure 5.3 shows the non-supplementation day mean rumen pH value recorded every minute over a 24 h period for all treatments. It can be observed that the rumen pH value of DLY dropped drastically right after supplementation (0800 h) remaining below threshold (dashed line) for most of the day. In contrast, rumen pH of alternate treatments did not drop after feeding (0800 h). Greater duration ($P \leq 0.01$) and area ($P \leq 0.02$) below the threshold were observed for DLY vs. LA or HA.

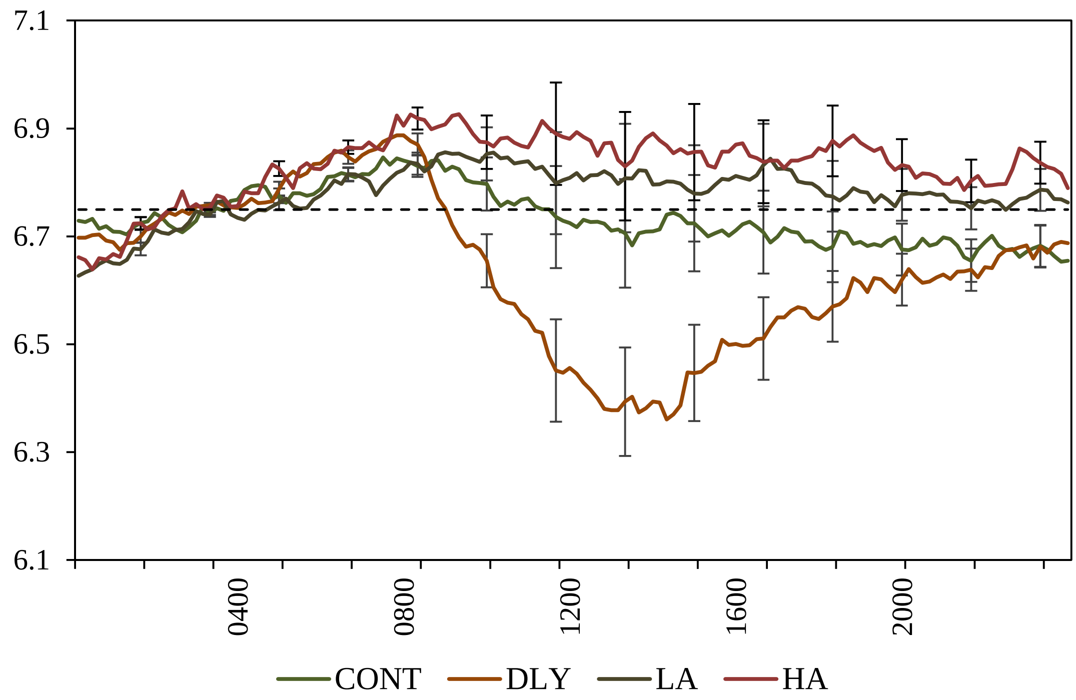

Figure 5.3. Effect on no supplementation day for alternate treatments of level of energy supplementation on daily rumen pH (mean ± SE) of beef heifers fed stockpiled grass hay.

Compared to DLY, supplementing 1.5 × the daily amount on alternate days had a lower effect on rumen pH than supplementing double the daily amount. Similar findings were observed by Chase and Hibberd (1989) who supplemented two levels (1.4 and 2.0 kg d^{-1}) of ground corn daily and twice the daily amount on alternate days to beef heifers fed low-quality hay. Although no effect of frequency or level × frequency was observed, they reported that the daily mean rumen pH value of heifers supplemented on alternate days was 0.10 pH units lower during supplementation day compared to non-supplementation day for the low level offered of ground corn. On the other hand, for the high level of supplementation, the daily mean rumen pH value of alternate supplemented heifers was 0.33 pH units lower during supplementation day compared to non-supplementation day.

The opposite response of rumen pH on supplementation and non-supplementation days observed for HA, has been reported previously for different supplemental energy sources and levels of supplementation. Beaty *et al.* (1994) observed that rumen pH of beef steers supplemented with equal weekly amounts of four rolled sorghum grain:soybean meal ratios offered either 3 × per week or daily, remained higher during non-supplementation days for alternate than for those supplemented daily; while during supplementation days, rumen pH of 3 × per week steers remained lower than those supplemented daily. Drewnoski and Poore (2012) measured the rumen fluid pH collected from the rumen mat and via suction strainer of steers fed fescue hay and supplemented with a soybean meal and corn gluten feed blend either daily or on alternate days. For both types of rumen fluid, it was found that the rumen pH of the alternate group was lower ($P < 0.05$) during supplementation days, and higher ($P < 0.05$) during non-supplementation days compared to daily supplemented steers. These contrasting rumen pH values observed during supplementation and non-supplementation days for alternate treatments can be attributed to the contrasting VFA concentrations during these days. In this study, both alternate treatments had opposite tendencies for VFA concentration (Tables 5.3.4 and 5.3.6) and rumen pH (Figures 5.8 and 5.9) during supplementation and non-supplementation days. As discussed previously, VFA absorption increases at lower rumen pH. In ruminants, restoring rumen pH is achieved by removing protons from the rumen through salivary and epithelial secretions. Buffering by the rumen epithelial is accomplished using both passive and active diffusion (via bicarbonate) of acetate, propionate, butyrate, and lactate (Aschenbach *et al.* 2011).

5.3.3. Total tract digestibility

Apparent digestibility

Total diet DM, OM, CP, and GE digestibility were greater ($P < 0.01$) for DLY compared to CON, but no difference ($P \geq 0.37$) was observed in fibre (NDF and ADF) digestibility (Table 5.5). This is consistent with Grigsby *et al.* (1993) and Garces-Yepez *et al.* (1997). Grigsby *et al.* (1993) found an increase ($P < 0.01$) in DM and OM digestibility, but no difference ($P = 0.25$) in NDF digestibility between beef steers fed low-quality bromegrass hay and those supplemented daily with four combinations of soybean hulls and ground corn. Similar results were reported by Garces-Yepez *et al.* (1997) when sheep fed bermudagrass hay were supplemented with either corn-soybean meal, wheat middlings, or soybean hulls. It was found that supplementation increased ($P < 0.01$) OM digestibility, but did not affect ($P = 0.93$) NDF digestibility. In the present study no difference ($P \geq 0.36$) in apparent digestibility was observed between DLY and HA. This is consistent for beef steers supplemented with twice the daily amount on alternate days as reported by Drewnoski and Poore (2012).

Since there was no effect for CON vs. DLY and DLY vs. HA on fibre digestibility, the reduction in hay DM intake observed can be attributed to the rate of NDF digestion rather than its total digestibility. Loy *et al.* (2007) reported that heifers fed grass hay had greater rate of *in situ* NDF disappearance (% h^{-1}) than those supplemented with dry-rolled corn or DDGS either daily or on alternate days. However, in that study no difference was observed among treatment for the extent (%) of *in situ* NDF disappearance after 96 h. As discussed previously, the rate of fibre digestion can be reduced by supplementing NFC, even though rumen pH levels do not go below 6.2 (Mould *et al.* 1983; Piwonka and Firkins 1993; Arroquy *et al.* 2005).

Table 5.5. Effect of frequency and level of energy supplementation on apparent nutrient digestibility coefficients of beef heifers fed stockpiled grass hay.

	Treatment[z]					*P* value (contrast)		
Item[x]	CON	DLY	LA	HA	SEM[y]	CON vs. DLY	DLY vs. LA	DLY vs. HA
Intake (kg d^{-1})								
Neutral detergent fibre	5.2	5.0	4.6	4.5	0.31	0.61	0.37	0.21
Gross energy (Mcal d^{-1})	33.0	37.2	33.7	34.0	2.10	0.11	0.17	0.20
Apparent digestibility (%)								
Dry matter	44.2	52.5	49.7	52.0	1.08	<0.01	0.03	0.63
Organic matter	47.3	55.1	52.6	54.9	1.06	<0.01	0.03	0.86
Crude protein	39.6	54.1	50.6	52.3	1.81	<0.01	0.20	0.50
Neutral detergent fibre	45.4	44.5	44.2	44.4	1.32	0.56	0.83	0.93
Acid detergent fibre	36.0	37.5	37.2	37.1	1.42	0.37	0.85	0.81
Gross energy	46.4	55.1	52.4	54.1	1.09	<0.01	0.03	0.36
DE (Mcal d^{-1})	15.4	20.5	17.5	18.4	1.02	<0.01	0.07	0.18
DE (Mcal kg^{-1} DM)	2.0	2.3	2.2	2.3	0.05	<0.01	0.03	0.40

[z]CON = no supplement offered; DLY = supplement offered daily at 0.6 % of BW; LA = supplement offered on alternate days at 0.9 % of BW; HA = supplement offered on alternate days at 1.2 % of BW. [y]SEM = standard error of mean. [x]DE = digestible energy.

Total diet DM, OM, and GE digestibility were greater ($P = 0.03$) for DLY compared to LA, but no difference ($P \geq 0.20$) was observed for CP, NDF, and ADF digestibility. Daily NDF and GE intakes were not different ($P \geq 0.17$) between DLY and LA. Moreover, as mentioned before, supplement constituted 23 and 19 % of total DM intake for DLY and LA respectively. For instance, a larger portion of the daily total GE intake of LA comes from forage which had a lower DM and OM digestibility as observed for CON. When determining the daily amount of DE, the difference between DLY and LA was decreased, with a tendency ($P = 0.07$) for DLY to be greater.

N Balance

Daily supplementation increased ($P < 0.01$) N intake compared to non-supplemented animals (Table 5.6). Also, retained N was 419 % greater ($P = 0.02$) for DLY compared to CON. No effects ($P > 0.19$) for DLY vs. LA or HA were observed on N excretion and retention. This is consistent with Drewnoski and Poore (2012) who found that steers supplemented daily had greater N intake and retention compared to those not supplemented, with no difference observed in N balance between daily and alternate supplementation. Although supplement offered was 25 % less for LA, no difference ($P = 0.12$) on N intake was observed compared to DLY.

Table 5.6. Effect of frequency and level of energy supplementation on nitrogen (N) balance of beef heifers fed stockpiled grass hay.

	Treatment[z]					*P* value (contrast)		
Item	CON	DLY	LA	HA	SEM[y]	CON vs. DLY	DLY vs. LA	DLY vs. HA
N intake (g d^{-1})	124	158	141	146	8.5	0.01	0.12	0.25
N excretion (g d^{-1})	116	123	118	124	9.1	0.37	0.54	0.91
% of N intake	94.2	78.7	85.3	84.3	4.04	0.02	0.28	0.35
Fecal N (g d^{-1})	74.1	72.4	69.6	69.2	4.90	0.72	0.57	0.52
% of N excretion	64.0	59.3	58.2	56.9	2.99	0.29	0.81	0.59
Urine N (g d^{-1})	41.7	50.7	48.6	54.8	6.27	0.22	0.77	0.56
% of N excretion	36.0	40.7	41.8	43.1	2.99	0.29	0.81	0.59
N retention (g d^{-1})	8.3	34.8	22.9	22.2	6.29	0.02	0.21	0.19
% of N intake	5.8	21.3	14.7	15.7	4.04	0.02	0.28	0.35

[z]CON = no supplement offered; DLY = supplement offered daily at 0.6 % of BW; LA = supplement offered on alternate days at 0.9 % of BW; HA = supplement offered on alternate days at 1.2 % of BW.
[y]SEM = standard error of mean.

5.4. Conclusions

In conclusion, supplementing digestible energy either daily or on alternate days decreased stockpiled grass hay intake of beef heifers, but increased digestibility of the diet and N balance. However, contrasting effects on hay DM intake, and rumen fermentation can be observed between supplementation and non-supplementation days when supplementing twice the daily amount of digestible energy on alternate days. The negative effects on hay DM intake and rumen fermentation can be reduced by decreasing the amount of supplement offered by 25 % on alternate days.

6. General Discussion & Conclusion

Stockpiled crested wheatgrass forage was not able to meet the nutrient requirements of yearling steers over the summer/fall period with energy as the most limiting nutrient. Averaged over the 2 years of grazing studies (2011 and 2012), CP and DE content of stockpiled crested wheatgrass were on average 11 and 13 % below the requirements (NRC 2000) for yearling steers to gain 1 kg daily. Moreover, this deficiency in nutrients was emphasized as the season advanced. At the start of both studies, CP and DE content of crested wheatgrass were on average 11 % above and 3 % below requirements, respectively; while at the end of both studies, CP and DE content of forage were 27 and 18 % below requirements, respectively.

By-product feeds that have been individually evaluated to be included in diets for beef cattle such as canola screenings, DDGS, grain screenings, oat and pea hulls, and wheat middlings can be used as ingredients for formulation of a pelleted supplement to be offered to growing beef cattle at a targeted level and performance. However, the variability among different batches of by-product feeds can lead to a discrepancy between formulated and final product. In 2011 grazing study, pelleted supplements were formulated to differ by 10 % in both starch and NDF content and to be equal in fat content. Resulting pellets differed by 8.3 and 6.7 % in starch and NDF content, and fat content between pellets differed by 1.2 %. A constant sampling of each by-product for determination of nutrient composition, through chemical analysis or technologies such as Near Infrared Spectroscopy (NIRS), can be a useful tool within the feeding industry in order to minimize this variation.

Forage utilization and intake were not affected by treatment in any of the two grazing studies. This can be attributed to the low-quality that the stockpiled crested wheatgrass averaged over the grazing period in both studies. It has been documented (Moore *et al*. 1999) that supplementation has a negative effect on forage intake as long as the TDN:CP ratio in the forage is less than 7. In both 2011 and 2012 grazing studies, this TDN:CP ratio in the forage were similar (6.5) to that value of 7 were supplementation does not affect forage intake. This was confirmed with study 3 where daily supplementation (DLY) had a lower hay dry matter intake (kg d^{-1}) compared to non-supplemented group (CON), and the TDN:CP ratio in the grass hay fed was 5.2 which is below the value (7) reported by Moore *et al*. (1999).

Energy supplementation improved animal performance of yearling steers grazing stockpiled crested wheatgrass pasture. However, energy source, supplementation frequency, and level of supplement offered on alternate days did not affect animal performance. In 2011 grazing study, supplemented steers had a greater performance compared to non-supplemented group, but the starch level or degradability of the fibre in the supplement (LS/HF and HD/LF) did not affect the response. The superior response of supplemented cattle compared to non-supplemented cattle can be attributed to greater rumen fluid VFA and ammonia-N concentrations, as well as digestibility and N retention observed for daily energy supplementation (DLY) compared to non-supplemented group (CON) in study 3. In 2012 grazing study, no difference in animal performance was observed among treatments. The lack of difference in forage DM intake observed among treatments in 2012 grazing study, as well as the lack of an effect of supplementation frequency (DLY vs. HA) on rumen fluid VFA and ammonia-N concentrations, digestibility coefficients and N-balance could have contributed to the similar animal performance between daily and alternate supplementation.

The lack of difference in animal performance for LA compared to both DLY and HA can also be attributed to the greater forage proportion in LA diet along with a more suitable rumen environment for fermentation. Reducing the amount of supplement offered on alternate days

(LA) increased the rumen fluid ammonia-N concentration compared to DLY. This increased level of ammonia-N in LA animals (5.8 mg dL^{-1}) was within the optimal range of rumen fluid ammonia-N (4.5 to 6.2 mg dL^{-1}) for both microbial growth and fibre digestion documented by Hoover (1986). Also, an overall daily mean rumen pH of LA similar to DLY, and the reduced change in daily rumen pH values between supplementation and non-supplementation days for LA could have improved rumen fermentation for alternate treatments.

Delivering supplement every day to grazing steers increased the production cost, decreasing the profitability and productivity of the system. However, supplementing energy at twice the daily amount on alternate days decreased the cost of production by reducing labour/machinery cost by 50 %. Moreover, reducing by 25 % the amount of supplement offered in alternate programs (1.5 × the daily amount) reduced production costs by reducing both labor/machinery and feeding.

In conclusion, a pelleted supplement can be formulated using various by-product feeds to be offered at a targeted level and performance. However, variation in the nutrient composition of the ingredients and constant sampling/analysis as well as reformulation should be considered. Animal performance and productivity of backgrounding steers grazing stockpiled crested wheatgrass pastures can be improved by supplementing digestible energy through offering this by-product feed pelleted supplement. Moreover, this supplement can be offered every 2nd day at a lower level (1.5 × the daily amount) without affecting animal performance, reducing costs of production, and increasing profits.

References

Adams, D. C., Clark, R. T., Klopfenstein, T. J. and Volesky, J. D. 1996. Matching the cow with forage resources. Rangelands. 57-62.

Adams, R. S. 1995. Dairy nutrition. (108-109) in Walker, C. (ed). Dairy Reference Manual. 3rd ed. Northeast Regional Agricultural Engineering Service, Ithaca, NY, USA.

Akin, D. E. 1986. Interaction of ruminal bacteria and fungi with southern forages. J. Anim. Sci. **63**: 962-977.

Allison, C. D. 1985. Factors affecting forage intake by range ruminants: A review. J. Range Manage. **38**: 305-311.

Anderson, R. V., Rasby, R. J., Klopfenstein, T. J., and Clark, R. T. 2005. An evaluation of production and economic efficiency of two beef systems from calving to slaughter. J. Anim. Sci. **83**: 694-704.

Anderson, S. J., Klopfenstein, T. J. and Wilkerson, V. A. 1988. Escape protein supplementation of yearling steers grazing smooth brome pastures. J. Anim. Sci. **66**: 237-242.

Arosemena, A., Depeters, E. J. and Fadel, J. G. 1995. Extent of Variability in Nutrient Composition within Selected by-Product Feedstuffs. Anim. Feed Sci. Technol. **54**: 103-120.

Arroquy, J. I., Cochran, R. C., Nagaraja, T. G., Titgemeyer, E. C. and Johnson, D. E. 2005. Effect of types of non-fiber carbohydrate on *in vitro* forage fiber digestion of low-quality grass hay. Anim. Feed Sci. Technol. **120**: 93-106.

Aschenbach, J.R., G.B. Penner, F. Stumpff, and G. Gäbel. 2011. Ruminant Nutrition Symposium: Role of fermentation acid absorption in the regulation of ruminal pH. J. Anim. Sci. **89**: 1092-1107.

Association of Official Analytical Chemists (AOAC). 2000. Official Methods of Analysis. 17th ed. AOAC International, Gaithersburg, MD.

Bandyk, C. A., Cochran, R. C., Wickersham, T. A., Titgemeyer, E. C., Farmer, C. G. and Higgins, J. J. 2001. Effect of ruminal vs. postruminal administration of degradable protein on utilization of low-quality forage by beef steers. J. Anim. Sci. **79**: 225-231.

Barnes, R. F., Nelson, C. J., Moore, K. J. and Collins, M. 2003. Forages: the science of grassland agriculture. Volume II. 6th ed. Blackwell Publishing. Ames, Iowa, USA.

Baron, V. S., Campbell, A. D., Bjorge, M. and Lastiwka, G. 2004. Stockpiling potential of perennial forage species adapted to the Canadian Western Prairie Parkland. Agron. J. **96**: 1545-1552.

Beames, R. M., Tait, R. M. and Litsky, J. 1986. Grain screenings as a dietary component for pigs and sheep. I. Botanical and chemical composition. Can. J. Anim. Sci. **66**: 473–481.

Beaty, J. L., Cochran, R. C., Lintzenich, B. A., Vanzant, E. S., Morrill, J. L., Brandt, R. T. Jr. and Johnson, D. E. 1994. Effect of frequency of supplementation and protein concentration in supplements on performance and digestion characteristics of beef cattle consuming low-quality forages. J. Anim. Sci. **72**: 2475-2486.

Beauchemin, K. A., Yang, W. Z., Morgavi, D. P., Ghorbani, G. R., Kautz, W. and Leedle, J. A. Z. 2003. Effectsof bacterial direct-fed microbials and yeast on site and extent of digestion, blood chemistry, and subclinical ruminal acidosis in feedlot cattle. J. Anim. Sci. **81**: 1628-1640.

Beck, P. A., Gunter, S. A. and Phillips, J. M. 2006. Evaluation of supplementation programs for growing catte grazing tall fescue. Prof. Anim. Sci. **22**: 325-333.

Belyea, R. L., Steevens, B. J., Restrepo, R. J. and Clubb, A. P. 1989. Variation in composition of by-product feeds. J. Dairy Sci. **72**: 2339-2345.

Blasi, D. A., Drouillard, J. S., Kuhl, G. L. and Wessels, R. H.. 1998. Wheat middlings in roughage-based or limit-fed, highconcentrate diets for growing calves. 1998 Cattlemen's Day, Rep. of Progress 804. pp 56-59. Kansas State Univ., Manhattan.

Bodine, T. N. and Purvis, H. T. 2003. Effects of supplemental energy and/or degradable intake protein on performance, grazing behavior, intake, digestibility, and fecal and blood indices by beef steers grazed on dormant native tallgrass prairie. J. Anim. Sci. **81**: 304-317.

Bodine, T. N., Purvis, H. T. and Lalman, D. L. 2001. Effects of supplement type on animal performance, forage intake, digestion, and ruminal measurements of growing beef cattle. J. Anim. Sci. **79**: 1041-1051.

Bohnert, D. W., DelCurto, T., Clark, A. A., Merrill, M. L., Falck, S. J. and Harmon, D. L. 2011. Protein supplementation of ruminants consuming low-quality cool- or warm-season forage: Differences in intake and digestibility. J. Anim. Sci. **89**: 3707-3717.

Bohnert, D. W., Schauer, C. S. and Delcurto, T. 2002. Influence of rumen protein degradability and supplementation frequency on performance and nitrogen use in ruminants consuming low quality forage: Cow performance and efficiency of nitrogen use in wethers. J. Anim. Sci. **80**: 1629-1637.

Boila, R. J. and Ingalls, J. R. 1994. The ruminal degradation of dry matter, nitrogen and amino acids in wheat-based distillers' dried grains in sacco. Anim. Feed Sci. Technol. **48**: 57-72.

Boniface, A. N., Murray, R. M. and Hogan, J. P. 1986. Optimal level of ammonia in the rumen liquid of cattle fed tropical pasture hay. Proc. Aust. Soc. Anim. Proc. **16**: 151-154.

Bowman, J. G. P. and Sanson, D. W. 1996. Starch or fiber based energy supplements for grazing ruminants. In: M. B. Judkins and F. T. McCollum III (Ed.) Proc. 3rd Grazing Livestock Nutrition Conf., Proc. West. Sect. Am. Soc. Anim. Sci. (Suppl. I): 118-135 (Abstr.).

Boyles, S. L., Caton, J. S., and Sime, D. M. 1998. Influence of soybean meal or increasing levels of barley supplementation on intake, ruminal fermentation, site of digestion, *in situ* forage degradibility, and duodenal amino acid flow in steers fed bromegrass hay. The Professional Animal Scientist. **14**: 118-126.

Broderick, G. A. and Kang, J. H. 1980. Automated simultaneous determination of ammonia and total amino acids in ruminal fluid and *in vitro* media. J. Dairy Sci. **89**: 513-520.

Canadian Council on Animal Care. 1993. Guide to the care and use of experimental animals. Vol 1. 2nd ed. Olfert, E. D., Cross, B. M. and McWilliam, A. A., Canadian Council on Animal Care. Ottawa, ON, Canada.

Canadian Grain Commission. 1996. Screenings, by-products, pelleted screenings. *In* Official grain grading guide. 1995 edition. Canadian Grain Commission, Industry Services Division. Winnipeg, MB.

Caton, J. S. and Dhuyvetter, D. V. 1997. Influence of energy supplementation on grazing ruminants: Requirements and responses. J. Anim. Sci. **75**: 533-542.

Chase, C. C. and Hibberd, C. A. 1989. Effects of level and frequency of maize supplementation on the utilization of low-quality grass by beef cows. Anim. Feed Sci. Technol. **24**: 129-139.

Chase, C.C. and Hibberd, C.A. 1987. Utilization of low-quality native grass hay by beef cows fed increasing quantities of corn grain. J. Anim. Sci. **65**: 557-566.

Cherney, J. H. and Kalenback, R. L. 2003. Forage systems for temperate humid areas. (277-290) *in* Barnes, R. F., Nelson, C. J., Moore, K. J. and Collins, M. (ed). Forages: the science of grassland agriculture. 6th. Blackwell Publishing, Ames, Iowa, USA.

Clark, L., Lardner, B. and Iwaasa, A. 2009. Wheat-based dried distillers grains supplementation in backgrounding and stocker programs. WBDC, Division of PAMI. Fact sheet # 2009-01.

Cook, W. C. and Stubbendieck, J. 1986. Range Research: Basic problems and techniques. Society for Range Manegment. Denver, Colorado. pp 122-123.

Cooke, R. F., Arthington, J. D., Araujo, D. B., Lamb, G. C. and Ealy, A. D. 2008. Effects of supplementation frequency on performance, reproductive and metabolic responses of Brahman crossbred females. J. Anim. Sci. **86**: 2296-2309.

Crosbie, G. B., Tarr, A. W., Portmann, P. A. and Rowe, J. B. 1984. Variation in hull composition and digestibility among oatgenotypes. Crop Sci. **25**: 678-680.

Darroch, C. S., Bell, J. M. and Keith, M. O. 1990. The effects of moist heat and ammonia on the chemical-composition and feeding value of extruded canola screenings for mice. Can. J. Anim. Sci. **70**: 267-277.

Daugherty, D. A., Britton, C. M. and Turner, H. A. 1982. Grazing manegment of crested wheatgrass range for yearling steers. J. Range Manage. **35**: 347-350.

DelCurto, T., Hess, B. W., Huston, J. E. and Olson, K. C. 2000. Optimum supplementation strategies for beef cattle consuming low-quality roughages in the western United States. J. Anim. Sci. **77**: 1-16.

Dijkstra, J., Boer, H., Van Bruchem, J., Bruining, M. and Tamminga, S. 1993. Absorption of volatile fatty acids from the rumen of lactating dairy cows as influenced by volatile fatty acid concentration, pH and rumen liquid volume. British Journal of Nutrition. **69**: 385-396.

Drewnoski, M. E. and Poore, M. H. 2012. Effects of supplementation frequency on ruminal fermentation, and digestion by steers fed medium quality hay and supplemented with soybean hulls and corn gluten feed blend. J. Anim. Sci. **90**: 881-891.

Drewnoski, M. E., Poore, M. H. and Benson, G. A. 2011. Effect of frequency of supplementation of a soyhulls and corn gluten feed blend on hay intake and performance of growing steers. Anim. Feed Sci. Technol. **164**: 38-44.

Ellis, W. C. 1978. Determinants of grazed forage intake and digestibility. J. Dairy Sci. **61**: 1828-1840.

Farmer, C. G., Cochran, R. C., Simms, D. D., Klevesahl, E. A., Wickersham, T. A. and Johnson, D. E. 2001. The effect of several supplementation frequencies on forage use and the performance of beef cattle consuming dormant tallgrass prairie forage. J. Anim. Sci. **79**: 2276-2285.

Forbes, J. M. 2007. Voluntary food intake and diet selection in farm animals. CABI.

Frame, J., Piñeiro, J and Laidlaw, A. S. 2004. Extending the grazing season. Pastos. 34: 5-30.

Frischknecht, N. C., Harris, L. E. and Woodward, H. K. 1953. Cattle gains and vegetal changes as influenced by grazing treatments on crested wheatgrass. J. of range Manage. **6**: 151-158.

Galloway, D. L. Sr., Goetsch, A. L., Forster L. A. Jr., Sun, W. and Johnson, Z. B. 1991. Feed intake and digestion by Holstein steers fed warm or cool season grass hays with corn, dried molasses, or wheat middlings. J. Dairy Sci. **74**:1038-1046.

Galloway, D. L., Goetsch, A. L., Forster, L. A., Sun, W. and Johnson, Z. B. 1991. Feed intake and digestion by Holstein steers fed warm or cool-season grass hays with corn, dried molasses, or wheat middlings. J. Dairy Sci. **74**: 1038-1046.

Garces-Yepez, P., Kunkle, W. E., Bates, D. B., Moore, J. E., Thatcher, W. W. and Sollenberger, L. E. 1997. Effects of supplemental energy source and amount on forage intake and performance by steers and intake and diet digestibility by sheep. J. Anim. Sci. **75**: 1918-1925.

Garleb, K. A., Bourquin, L. D., Hsu, J. T., Wagner, G. W., Schmidt, S. J. and Fahey, G. C. Jr. 1991. Isolation and chemical analyses of nonfermented fiber fractions of oat hulls and cottonseed hulls. J. Anim. Sci. **69**: 1255-1271.

Ghorbani, G. R., Morgavi, D. P., Beauchemin, K. A. and Leedle, J. A. Z. 2002. Effectsof bacterial direct-fed microbials on ruminal fermentation, blood variables, and the microbial populationsof feedlot cattle. J. Anim. Sci. **80**: 1977-1985.

Glover, D. E., Kielly, G. A., Jefferson, P. G. and Cohen, R. D. H. 2004. Agronomic characteristics and nutritive value of 11 grasses grown with irrigation on a saline soil in southwestern Saskatchewan. Can. J. Plant Sci. **84**: 1037-1050.

Grant, R. J., and D. R. Mertens. 1992. Influence of buffer pH and raw corn starch addition on *in vitro* fiber digestion kinetics. J. Dairy Sci. **75**: 2762‑2768.

Grasser, L. A., Fadel, J. G., Garnett, I. and DePeters, E. J. 1995. Quantity and economic importance of nine selected by-products used in California dairy rations. J. Dairy Sci. **78**: 962-971.

Grigsby, K. N., Kerley, M. S., Paterson, J. A. and Weigel, J. C. 1993. Combinations of starch and digestible fiber in supplements for steers consuming a low-quality bromegrass hay diet. J. Anim. Sci. **71**: 1057-1064.

Gunter, S. A., Cassida, K. A., Beck, P. A. and Phillips, J. M. 2002. Winter-annual pasture as a supplement for beef cows. J. Anim. Sci. **80**: 1157-1165.

Hall, M. B. 2008. Determination of starch, including maltooligosaccharides, in animal feeds: A comparison of methods and a recommended method for AOAC collaborative study. J. AOAC Int. **92**: 42-49.

Ham, G. A., Stock, R. A., Klopfenstein, T. J., Larson, E. M., Shain, D. H. and Huffman, R. P. 1994. Wet corn distillers byproducts compared with dried corn distillers grains with solubles as a source of protein and energy for ruminants. J. Anim. Sci. **72**: 3246-3257.

Harfoot, C. G. and Hazlewood, G. P. 1997. Lipid metabolism in the rumen. In The rumen microbial ecosystem. Springer Netherlands. pp. 382-426.

Hart, R.H., Abdalla, O.M., Clark, D.H., Marshall, M.B., Hamid, M.H.,Hager, J.A. and Waggoner, Jr., J.W. 1983. Quality of forage and cattle diets on the Wyoming high plains. J. Range Manage. **36**: 46-51.

Havstad, K. M. and Malechek, J. C. 1982. Energy-expenditure by heifers grazing crested wheatgrass of diminishing availability. J Range Manage. **35**: 447-450.

Hess, B. W., Moss, G. E. and Rule, D. C. 2008. A decade of development in the area of fat supplementation research with beef cattle and sheep. J. Anim. Sci. **86**: E188-E204.

Hoffman, L., Ries, R. E., Karn, J. F. and Frank, A. B. 1993. Comparison of seeded and native pastures grazed from mid-May through September. J. Range Manage. **46**: 251-254.

Holecheck, J. L. and Carlton, H. H. 1986. Supplementing range livestock. Rangelands. **8**: 29.33.

Holechek, J. L. 1981. Crested wheatgrass. Rangelands. **3**: 151-153.

Holechek, J. L. and Herbel, C. H. 1986. Supplementing range livestock. Rangelands. **8**: 29-33.

Hoover, W. H. 1986. Chemical factors involved in ruminal fiber digestion. J. Dairy Sci. **69**: 2755-2766.

Horn, G. W. and F. T. McCollum. 1987. Energy supplementation of grazing ruminants. Proc. Graz. Nutr. Conf. Jackson Hole, WY.

Horn, G. W., Cravey, M. D., McCollum, F. T., Strasia, C. A., Krenzer, E. G., Jr. and Claypool, P. L. 1995. Influence of high-starch vs. high-fiber energy supplements on performance of stocker cattle grazing wheat pasture and subsequent feedlot performance. J. Anim. Sci. **73**: 45-54.

Hsu, J. T., Faulkner, D. B., Garleb, K. A., Barclay, R. A., Fahey, G. C. and Berger, L. L. 1987. Evaluation of corn fiber, cottonseed hulls, oat hulls and soybean hulls as roughage sources for ruminants. J. Anim. Sci. **65**: 244-255.

Huston, J.E., Lippke, H., Forbes, T.D.A., Holloway, J.W. and Machen, R.V. 1999. Effects of supplemental feeding interval on adult cows in western Texas. J. Anim. Sci. **77**: 3057–3067.

Jasmer, G. E. and Holecheck, J. L. 1984. Determining grazing intensity on rangeland. J. Soil Water Conserv. **39**: 32-35.

Jimenez-Moreno, E., Chamorro, S., Frikha, M., Safaa, H. M., Lazaro, R. and Mateos, G. G. 2011. Effects of increasing levels of pea hulls in the diet on productive performance, development of the gastrointestinal tract, and nutrient retention of broilers from one to eighteen days of age. Anim Feed Sci. Technol. **168**:100-112.

Johnson, J. A., Caton, J. S., Poland, W., Kirby, D. R. and Dhuyvetter, D. V. 1998. Influence of season on dietary composition, intake, and digestion by beef steers grazing mixed-grass prairie in the northern Great Plains. J. Anim. Sci. **76**: 1682-1690.

Johnson, J. and Wand, C. 1999. Stockpiling perennial forages for fall and winter grazing. Agridex 131/53. Factsheet, Field Crops. Ontario Ministry of Agriculture, Food and Rural Affairs. Toronto, ON, Canada.

Jones, A. L., Goetsch, A. L., Stokes, S. R. and Colberg, M. 1988. Intake and digestion in cattle fed warm-or cool-season grass hay with or without supplemental grain. J. Anim. Sci. **66**: 194-203.

Jung, H. G. and Allen, M. S. 1995. Characteristics of plant cell walls affecting intake and digestibility of forages by ruminants. J. Anim. Sci. **73**: 2774-2790.

Karges, K. K., Klopfenstein, T. J., Wilkerson, V. A. and Clanton, D. C. 1992. Effects of ruminally degradable and escape protein supplements on steers grazing summer native range. J. Anim. Sci. **70**: 1957-1964.

Karn, J. F., Ries, R. E. Hofmann, L. 1999. Season-long grazing of seeded cool-season pastures in the northern Great Plains. J. Range Manage. **52**: 235-240.

Klopfenstein, T. 1996. Need for escape protein by grazing cattle. Anim. Feed Sci. Technol. **60**: 191-199.

Klopfenstein, T. J., Erickson, G. E. and Bremer, V. R. 2008. Board-Invited Review: Use of distillers by-products in the beef cattle feeding industry. J. Anim. Sci. **86**: 1223-1231.

Koster, H. H., Cochran, R. C., Titgemeyer, E. C., Vanzant, E. S., Abdelgadir, I. and St-Jean, G. 1996. Effect of increasing degradable intake protein on intake and digestion of low-quality, tallgrass-prairie forage by beef cows. J. Anim. Sci. **74**: 2473-2481.

Krause, K. M. and Combs, D. K. 2003. Effects of forage particle size, forage source, and grain fermentability on performance and ruminal pH in midlactation cows. J. Diry Sci. **86**: 1382-1397.

Krehbiel, C.R., Ferrell, C.L. and Freetly, H.C. 1998. Effects of frequency of supplementation on dry matter intake and net portal and hepatic flux of nutrients in mature ewes that consume low-quality forage. J. Anim. Sci. **76**: 2464-2473.

Krishnamoorthy, U., Muscato, T. V., Sniffen, C. J. and Van Soest, P. J. 1982. Nitrogen fractions in selected feedstuffs. J. Dairy Sci. **65**: 217-225.

Kromann, R. P., Warner, K. O., Wilson, T. R., Martin, E. L. and Hillers, J. K. 1977. Digestible, metabolizable and net energy values of pea scalpings and wheat straw in lambs. J. Anim. Sci. **45**: 855-862.

Kunkle, W. E., Johns, J. T; Poore, M. H. and Herd, D. B. 2000. Designing supplementation programs for beef cattle fed forage based diets. J. Anim. Sci. **77**: 1-11.

Kunkle, W.E., Stewart, R.L., Brown, W.F., 1995. Using byproduct feeds in supplementation programs. In: Proceedings of Florida Beef Cattle Short Course. University of Florida, Gainesville, pp. 89-96.

Lacefield, G., Smith, R., Henning, J., Johns, J. and Burris, R. 2006. Stockpiling for fall and winter pasture. University of Kentucky Cooperative Extension Service. AGR-162.

Little, R. C., Henry, P. R. and Ammerman, C. B. 1998. Statistical analysis of repeated measures data using SAS procedures. J. Anim. Sci. **76**: 1216-1231.

Loy, T.W., Klopfenstein, T.J., Erickson, G.E., Macken, C.N. and MacDonald, J.C. 2008. Effect of supplemental energy source and frequency on growing calf performance. J. Anim. Sci. **86**: 3504–3510.

Loy, T.W., MacDonald, J.C., Klopfenstein, T.J. and Erickson, G.E. 2007. Effect of distillers grains or corn supplementation frequency on forage intake and digestibility. J. Anim. Sci. **85**: 2625-2630.

Marx, T. A., McKinnon, J. J., Mustafa, A. F., Christensen, D. A. and Racz, V. J. 2000. The feeding value of grain screenings for ruminants: Chemical composition and nutrient utilization. Can. J. Anim. Sci. **80**: 673-680.

McDowell, L. R. 1996. Feeding minerals to cattle on pasture. Anim. Feed Sci. Technol. **60**: 247-271.

McKinnon, J. J. and Walker, A. M. 2008. Comparison of wheat-based dried distillers' grain with solubles to barley as an energy source for backgrounding cattle. Can. J. Anim. Sci. **88**: 721-724.

Memmott, K. L., Anderson, V. J. and Fugal, R. 2011. Seasonal dynamics of forage shrub nutrients. Rangelands. **33**: 12-16.

Miller, A. J., Faulkner, D. B., Knipe, R. K; Strohbehn, D. R., Parrett, D. F. and Berger, L. L. 2001. Critical control points for profitability in the cow-calf enterprise. Prof. Anim. Sci. **17**: 295-302.

Minson, D. J. 1990. Forages in Ruminant Nutrition. Academic Press. San Diego, USA.

Minson, D. J. and McDonald, C. K. 1987. Estimating forage intake from the growth of beef cattle. Tropical Grasslands. **21**: 116-122.

Moore, J. E., Brant, M. H., Kunkle, W. E. and Hopkins, D. I. 1999. Effects of supplementation on voluntary forage intake, diet digestibility, and animal performance. J. Anim. Sci. 77(Suppl.): 122-135.

Moriel, P., Cooke, R. F., Bohnert, D. W., Vendramini, J. M. B. and Arthington, J. D. 2012. Effects of energy supplementation frequency and forage quality on performance, reproductive, and physiological responses of replacement beef heifers. J. Anim. Sci. **90**: 2371-2380.

Mould, F. L. and Orskov, E. R. 1983. Manipulation of rumen fluid pH and its influence on cellulolysis in sacco, dry matter degradation and the rumen microflora of sheep offered either hay or concentrate. Anim. Feed Sci. Technol. **10**: 1-14.

Mould, F.L., Ørskov, E.R., Mann, S.O., 1983. Associative effects of mixed feeds. I. Effects of type and level of supplementation and the influence of the rumen fluid pH on cellulolysis *in vivo* and dry matter digestion of various roughages. Anim. Feed Sci. Technol. **10**: 15-30

Mourino, F., Akkarawongosa, R., Weimer, P. J., 1997. Initial pH as a determinant of cellulose digestion rate by mixed ruminal microorganisms in vivo. J. Dairy Sci. **84**: 848-859.

Mustafa, A. F., McKinnon, J. J. and Christensen, D. A. 2000a. The nutritive value of thin stillage and wet distillers' grains for ruminants - Review. Asian-Australasian Journal of Animal Sciences. **13**: 1609-1618.

Mustafa, A. F., McKinnon, J. J., Ingledew, M. W. and Christensen, D. A. 2000b. The nutritive value for ruminants of thin stillage and distillers' grains derived from wheat, rye, triticale and barley. J. Sci. Food Agric. **80**: 607-613.

National Research Council (NRC). 2000. Nutrient Requirements of Beef Cattle. Revised 7th ed. National Academy Press, Washington, DC.

Nuez-Ortin, W. G. and Yu, P. 2009b. Nutrient variation and availability of wheat DDGS, corn DDGS and blend DDGS from bioethanol plants. J. Sci. Food Agric. **89**: 1754-1761.

Ojowi, M. O., Christensen, D. A., McKinnon, J. J. and Mustafa, A. F. 1996. Thin stillage from wheat-based ethanol production as a nutrient supplement for cattle grazing crested wheatgrass pastures. Can. J. Anim. Sci. **76**: 547-553.

Ojowi, M. O., McKinnon, J. J., Mustafa, A. F. and Christensen, D. A. 1997. Evaluation of wheat-based wet distillers' grains for feedlot cattle. Can. J. Anim. Sci. **77**: 447-454.

Olson, K. C., Cochran, R. C., Jones, T. J., Vanzant, E. S., Titgemeyer, E. C. and Johnson, D. E. 1999. Effects of ruminal administration of supplemental degradable intake protein and starch on utilization of low-quality warm season grass hay by beef steers. J. Anim. Sci. **77**: 1016-1025.

Ortin, W. G. N. and Yu, P. Q. 2009. Nutrient variation and availability of wheat DDGS, corn DDGS and blend DDGS from bioethanol plants. J. Sci. Food Agric. **89**: 1754-1761.

Osuji, P. O. 1974. The physiology of eating and the energy expenditure of the ruminant at pasture. J. Range Manage. **27**: 437-443.

Palmquist, D. L. 1994. The role of dietary fats in efficiency of ruminants. J. Nutr. **124**: 1377S-1382S.

Park, K. K., Krysl, L. J., McCracken, B. A., Judkins, M. B. and Holcombe, D. W. 1994. Steers grazing intermediate wheatgrass at various stages of maturity: effects on nutrient quality, forage intake, digesta kinetics, ruminal fermentation, and serum hormones and metabolites. J. Anim. Sci. **72**: 478-486.

Paterson, J. A., Belyea, R. L.,. Bowman, J. P., Kerley, M. S and Williams, S. E. 1994. The impact of forage quality and supplementation regimen on ruminant animal intake and performance. In: G. C. Fahey *et al.* (Ed.) Forage Quality, Evaluation, and Utilization. ASA, CSSA, SSSA, Madison, WI.

Pavan, E., Duckett, S. K. and Andrae, J. G. 2007. Corn oil supplementation to steers grazing endophyte-free tall fescue. I. Effects on *in vivo* digestibility, performance and carcass traits. J. Anim. Sci. **85**: 1330-1339.

Penner, G. B., Beauchemin, K. A. and Mutsvangwa, T. 2006. An evaluation of the accuracy and precision of a stand-alone submersible continuous ruminal pH measurement system. J. Dairy Sci. **89**: 2132–2140.

Penner, G. B., Beauchemin, K. A. and Mutsvangwa, T. 2007. Severity of ruminal acidosis in primiparous Holstein cows during the periparturient period. J. Dairy Sci. **90**: 365-375.

Piwonka, E.J. and Firkins, J.L., 1993. Effect of glucose fermentation on fiber digestion by ruminal microorganisms *in vitro*. J. Dairy Sci. **79**: 2196-2206.

Poore, M. H., Benson, G. A., Scott, M. E. and Green, J. T. 2000. Production and use of stockpiled fescue to reduce beef cattle production costs. J. Anim. Sci. **79**: 1-11.

Poore, M. H., Scott, M. E. and Green, J. T. 2006. Performance of beef heifers grazing stockpiled fescue as influenced by supplemental whole cottonseed. J. Anim. Sci. **84**: 1613-1625.

Pordomingo, A. J., Wallace, J. D., Freeman, A. S. and Galyean, M. L. 1991. Supplemental corn grain for steers grazing native rangeland during summer. J. Anim. Sci. **69**: 1678-1687.

Pylot, S. J., McKinnon, J. J., McAllister, T. A., Mustafa, A. F., Popp, J. and Christensen, D. A. 2000a. Canola screenings as a fiber source in barley-based feedlot diets: effects on rumen fermentation and performance of steers. Can. J. Anim. Sci. **80**: 161-168.

Pylot, S., McKinnon, J. J., Mustafa, A. F., Racz, V. J. and Christensen, D. A. 2000b. Effects of processing and fat content of coarse canola screenings on voluntary intake and total tract nutrient digestibility of beef steers. Can. J. Anim. Sci. **80**: 153-159.

Reed, J. J., O'Neil, M. R., Lardy, G. P., Vonnahme, K. A., Reynolds, L. P. and Caton, J. S. 2007. Effect of undegradable intake protein supplementation on intake, digestion, microbial efficiency, *in situ* disappearance, and plasma hormones and metabolites in steers fed low-quality grass hay. J. Anim. Sci. **85**: 1092-1101.

Reid, R. L. and Jung, G. A. 1982. Problems of animal production from temperate pastures. In: J. B. Hacker (Ed.). Nutritional limits to animal production from pastures: Proceedings of an international symposium held at St. Lucia, Queensland, Australia, August 24^{th}-28^{th}, 1981. Commonwealth Agricultural Bureaux. Slough, UK. pp 21-43.

Riesterer, J. L., Undersander, D. J., Casler, M. D. and Combs, D. K. 2000. Forage yield of stockpiled perennial grasses in the upper midwest USA. Agron. J. **92**: 740-747.

Rogler, G. A. and Lorenz, R. J. 1983. Crested wheatgrass – Early history in the United States. J. Range Manage. **36**: 91-93.

Russell, J. B. and Wilson, D. B. 1996. Why are ruminal cellulolytic bacteria unable to digest cellulose at low pH? J. Dairy Sci. **79**: 1503-1509.

Sainz, R. D., De la Torre, F. and Oltjen, J. W. 1995. Compensatory growth and carcass quality in growth-restricted and refed beef steers. J. Anim. Sci. **73**: 2971-2979.

Salmon, R.E. 1985. Effects of pelleting, added sodium bentonite and fat in a wheat-based diet on performance and carcass characteristics of small white turkeys. Anim. Feed Sci. Technol. **12**: 223-232.

Sanson, D. W., Clanton, D. C. and Rush, I. G. 1990. Intake and digestion of low-quality meadow hay by steers and performance of cows on native range when fed protein supplements containing various levels of corn. J. Anim. Sci. **68**: 595-603.

Saskatchewan Ministry of Agriculture (SMA). 2012. Farm machinery custom and rental rate guide. 2012-2013. Regina, SK, Canada.

Scholljegerdes, E. J. and Kronberg, S. L. 2010. Effect of supplemental ground flaxseed fed to beef cattle grazing summer native range on the northern Great Plains. J. Anim. Sci. **88**: 2108-2121.

Schroeder, G. F., and Titgemeyer, E. C. 2008. Interaction between protein and energy supply on protein utilization in growing cattle: a review. Livestock Sci. **114**: 1-10.

Smoliak, S. and Bjorge, M. 1981. Hay and Pasture Crops. Pages 7-70 *in* Alberta Forage Manual. Alberta Agriculture, Food and Rural Development, Edmonton, Alberta.

Snedecor, G. y Cochran, W. 1989. Statistical methods. Eighth edition. Iowa State University Press. USA. 503 p.

Spiehs, M. J., Whitney, M. H. and Shurson, G. C. 2002. Nutrient database for distiller's dried grains with solubles produced from new ethanol plants in Minnesota and South Dakota. J. Anim. Sci. **80**: 2639-2645.

Stalker, L. A., Adams, D. C. and. Klopfenstein, T. J. 2009. Influence of distillers dried grain supplementation frequency on forage digestibility and growth performance of beef cattle. Prof. Anim. Sci. **25**: 289–295.

Stanford, K., Wallins, G. L., Smart, W. G. and McAllister, T. A. 2000. Effects of feeding canola screenings on apparent digestibility, growth performance and carcass characteristics of feedlot lambs. Can. J. Anim. Sci. **80**: 355-362.

Stockdale, C. R. and Rathbone, S. 1992. Comparisons of methods for estimating *in vivo* digestibility of feedstuffs in dairy cattle. Anim. Feed Sci. Technol. **40**: 1-11.

Sunvold, G. D., Cochran, R. C. and Vanzant, E. S. 1991. Evaluation of wheat middlings as a supplement for beef-cattle consuming dormant bluestem-range forage. J. Anim. Sci. **69**: 3044-3054.

Thomas, M., Van Vliet, T., Van der Poel, A. F. B. 1998. Physical quality of pelleted animal feed 3. Contribution of feedstuff components. Anim. Feed Sci. Technol. **70**: 59-78.

Thompson, R. K., McKinnon, J. J., Mustafa, A. F., Maenz, D. D., Racz, V. J. and Christensen, D. A. 2002. Chemical composition, ruminal kinetic parameters, and nutrient digestibility of ammonia treated oat hulls. Can. J. Anim. Sci. **82**: 103-109.

Thompson, R. K., Mustafa, A. F., Mckinnon, J. J., Maenz, D. and Rossnagel, B. 2000. Genotypic differences in chemical compostion and ruminal degradability of oat hulls. Can. J. Anim. Sci. **80**: 377-379.

Titgemeyer, E. C., Bourquin, L. D., Fahey, G. C. and Garleb, K. A. 1991. Fermentability of various fiber sources by human fecal bacteria in vitro. Am. J. Clin. Nutr. **53**: 1418-1424.

Van De Kerckhove, A. Y. 2012. Effects of supplementing beef cows grazing forages with wheat based dried distillers grains with solubles on animal performance, forage intake and rumen metabolism. M. Sc. Thesis, University of Saskatchewan, Sk.

Van Soest, P. J. 1994. Nutritional ecology of the ruminant. 2nd ed. Cornell University Press. Ithaca, NY, USA.

Wallace, J. D., Hubert, F. J. and Raleigh, R. J. 1963. The response of yearling cattle on crested wheatgrass pasture to energy, protein and sodium supplementation. J. of Range Manage. **16**: 1-5.

Walter, L. J. 2010. Comparison of wheat or corn dried distillers grains with solubles on performance, carcass characteristics, rumen fermentation parameters and diet digestibility of feedlot cattle. M. Sc. Thesis, University of Saskatchewan, Sk.

Weir, W. C. and Torell, D. T. 1959. Selective grazing by sheep as shown by a comparison of the chemical composition of range and pasture forage obtained by hand and that collected by esophageal-fistulated sheep. J. Anim. Sci. **18**: 641-649.

Wood, J. F. 1987. The functional properties of feed raw materials and their effect on the production and quality of feed pellets. Anim. Feed. Sci. Technol. **18**: 1- 17.

Wright, S. B. M. 1986. A study of nitrogen fertilization of grazed pasture in Saskatchewan. M. Sc. Thesis, University of Saskatvhewan, Saskatoon, Sk.

ZoBell, D. R., Goonewardene, L. A., Olson, K. C., Stonecipher, C. A. and Wiedmeier, R. D. 2003. Effects of feeding wheat middlings on production, digestibility, ruminal fermentation and carcass characteristics in beef cattle. Can. J. Anim. Sci. **83**: 551-557.

Appendix

Equation A.1. CP_ADF equation for all-forage diets (NRC 2000)

$$DMI\ (kg)/SBW^{0.75}\ (kg) = 0.002774 * CP\ (\%) - 0.000864 * ADF\ (\%) + 0.09826$$

Equation A.2. Penn State grass-legume equation (Adams 1995)

$$DE\ (Mcal\ kg^{-1}) = 0.04409\ x\ (4.898 + [1.044 - \{0.0119\ x\ ADF(\%)\}]\ x\ 89.796$$

Equation A.3. Penn State cereal grain equation (Adams 1995)

$$DE\ (Mcal\ kg^{-1}) = 0.04409\ x\ (4.898 + [0.9265 - \{0.00793\ x\ ADF(\%)\}]\ x\ 89.796$$

Equation A.4. Estimating forage intake from the growth of beef cattle (Minson and McDonald 1987)

$$DMI\ (kg\ d^{-1}) = (1.185 + 0.00454 BW\ (kg) - 0.0000026\ BW^{2} + 0.315\ ADG)^{2}$$

Table A.1. Nutrient composition of by-product feeds used as ingredients for pelleted supplements formulation.

Item[z]		DM (%)	CP (%DM)	Sol. Prot. (%CP)	ADF (%DM)	NDF (%DM)	Starch (%DM)	EE (%DM)	TDN (%DM)	Ash (%DM)	Ca (%DM)	P (%DM)
Canola screenings	n	6	6	6	6	6	6	**6**	6	6	6	6
	Avg	92.18	21.35	26.36	16.65	26.07	2.42	42.76	137.16	4.34	0.39	0.66
	SD	2.84	1.23	6.77	2.59	2.80	1.06	5.13	9.65	0.39	0.03	0.07
DDGS	n	8	8	8	8	8	8	8	8	8	8	8
	Avg	89.44	37.21	16.89	13.89	28.04	4.35	8.79	83.46	5.56	0.14	0.90
	SD	0.96	2.27	1.58	1.12	1.09	2.78	1.36	3.89	0.61	0.04	0.06
Oat hulls	n	8	8	8	8	8	8	8	8	8	8	8
	Avg	91.11	4.85	32.44	41.43	74.08	10.80	1.68	53.93	5.13	0.12	0.12
	SD	0.39	0.54	3.89	1.75	2.68	1.41	0.37	1.36	0.35	0.02	0.02
Pea screenings	n	10	10	10	10	10	10	10	10	10	10	10
	Avg	90.40	20.31	49.66	16.42	25.63	31.67	5.14	77.20	5.69	0.32	0.42
	SD	0.66	2.35	9.19	3.05	3.94	4.63	1.23	2.55	1.72	0.12	0.03
Grain screenings	n	10	10	10	10	10	10	10	10	10	10	10
	Avg	90.64	14.93	31.83	20.13	33.89	35.92	5.71	74.55	5.91	0.28	0.37
	SD	0.51	1.14	1.68	3.77	3.54	5.39	0.69	2.44	1.00	0.14	0.04
Wheat middlings	n	9	9	9	9	9	9	9	9	9	9	9
	Avg	88.84	15.25	27.83	4.51	14.96	60.97	2.81	82.77	2.64	0.07	0.38
	SD	0.51	1.60	5.33	1.07	1.84	3.49	0.55	1.91	0.64	0.03	0.05
Pea hulls	n	1	1	1	1	1	1	-	-	-	-	-
	Avg	88.45	11.97	54.32	55.18	59.81	6.32	-	-	-	-	-
	SD	-	-	-	-	-	-	-	-	-	-	-
Peas	-	88.00	24.43	45.00	9.09	14.77	47.73	1.70	88.64	5.11	0.91	0.47

[z]DDGS = dried distiller's grain with solubles.

Table A.2. Nutrient composition of stockpiled crested wheatgrass pasture sampled during summer/fall of 2007 and 2008.

Date		CP (%DM)	NDF (%DM)	ADF (%DM)	TDN (%DM)	Ca (%DM)	P (%DM)	DE (Mcal kg^{-1})
	n	7	7	7	7	7	7	7
Aug 07	**Avg**	9.3	62.1	35.9	60.2	0.34	0.14	2.7
	SD	2.3	2.0	1.7	0.9	0.09	0.03	0.0
	n	6	6	6	6	6	6	6
Sep 07	**Avg**	7.9	65.9	42.2	57.0	0.37	0.09	2.5
	SD	0.9	4.0	3.8	1.8	0.10	0.02	0.1
	n	3	3	3	3	3	3	3
Oct 07	**Avg**	6.4	66.4	42.9	56.7	0.43	0.08	2.5
	SD	0.4	2.6	4.0	2.0	0.05	0.01	0.1
	n	5	5	5	5	5	5	5
Aug 08	**Avg**	10.8	60.3	33.5	61.4	0.45	0.16	2.7
	SD	1.4	2.0	1.8	0.9	0.10	0.04	0.0
	n	6	6	6	6	6	6	6
Sep 08	**Avg**	7.4	66.8	41.6	57.4	0.44	0.09	2.5
	SD	0.3	3.5	2.4	1.2	0.04	0.02	0.1
	n	3	3	3	3	3	3	3
Oct 08	**Avg**	6.4	67.6	42.0	57.5	0.43	0.09	2.5
	SD	0.3	2.7	2.7	0.9	0.01	0.01	0.1
	n	30	30	30	30	30	30	30
	Avg	8.3	64.5	39.2	58.6	0.40	0.11	2.6
Total	**SD**	1.94	3.81	4.42	2.17	0.09	0.04	0.10
	Min	6.0	58.6	31.6	54.5	0.21	0.06	2.4
	Max	12.5	71.1	47.5	62.4	0.59	0.21	2.7

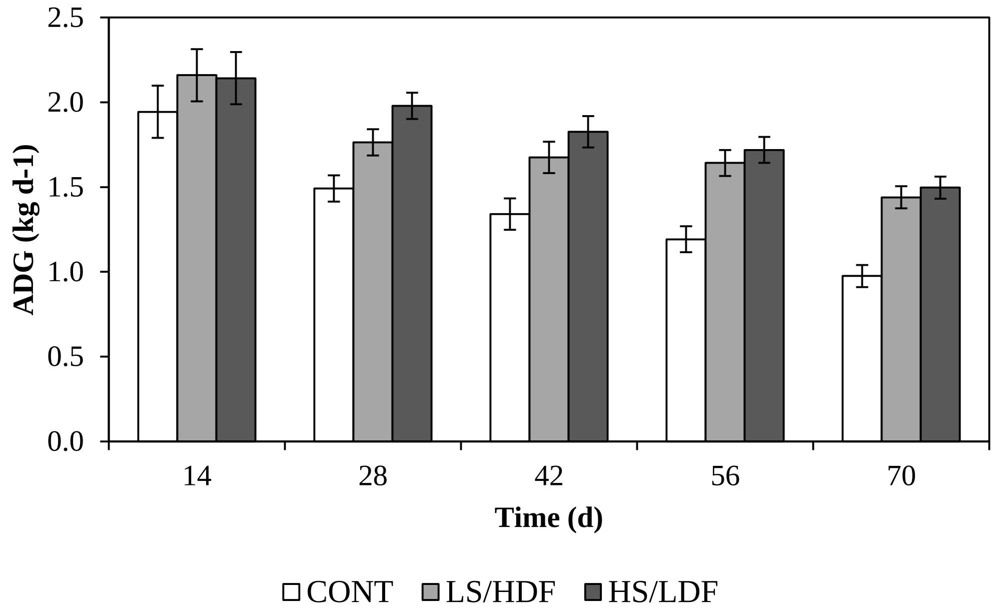

Figure A.1. Effect of treatment across time on cumulative ADG (LSM ± SE) of steers grazing stockpiled crested wheatgrass pastures (2011).